Pacific Science Congress
Proceedings
LIBRARY
MAR 16 1960
FISH & WILDLIFE SERVICE
9th - 1957
Vol. 16
1957 -
9th
V. 1

PROCEEDINGS

of the

NINTH PACIFIC SCIENCE CONGRESS

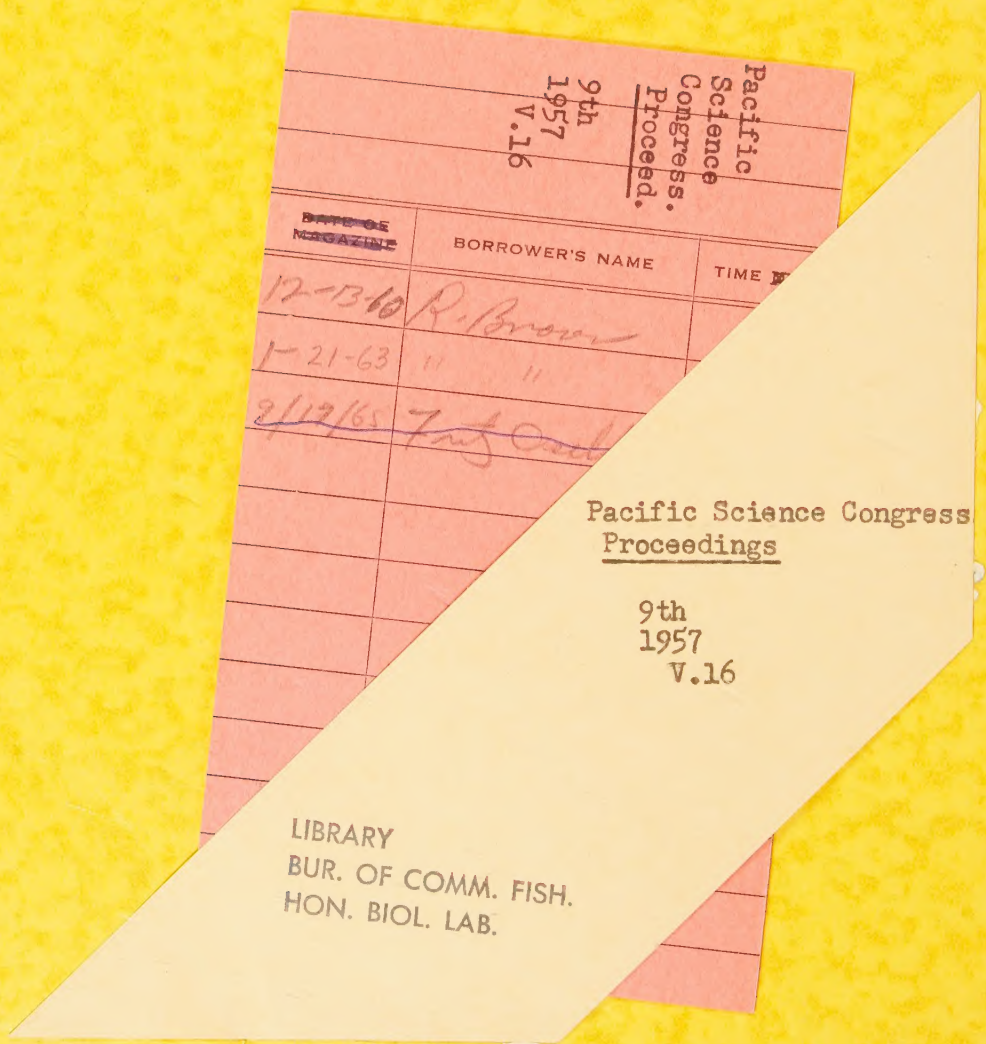
of the

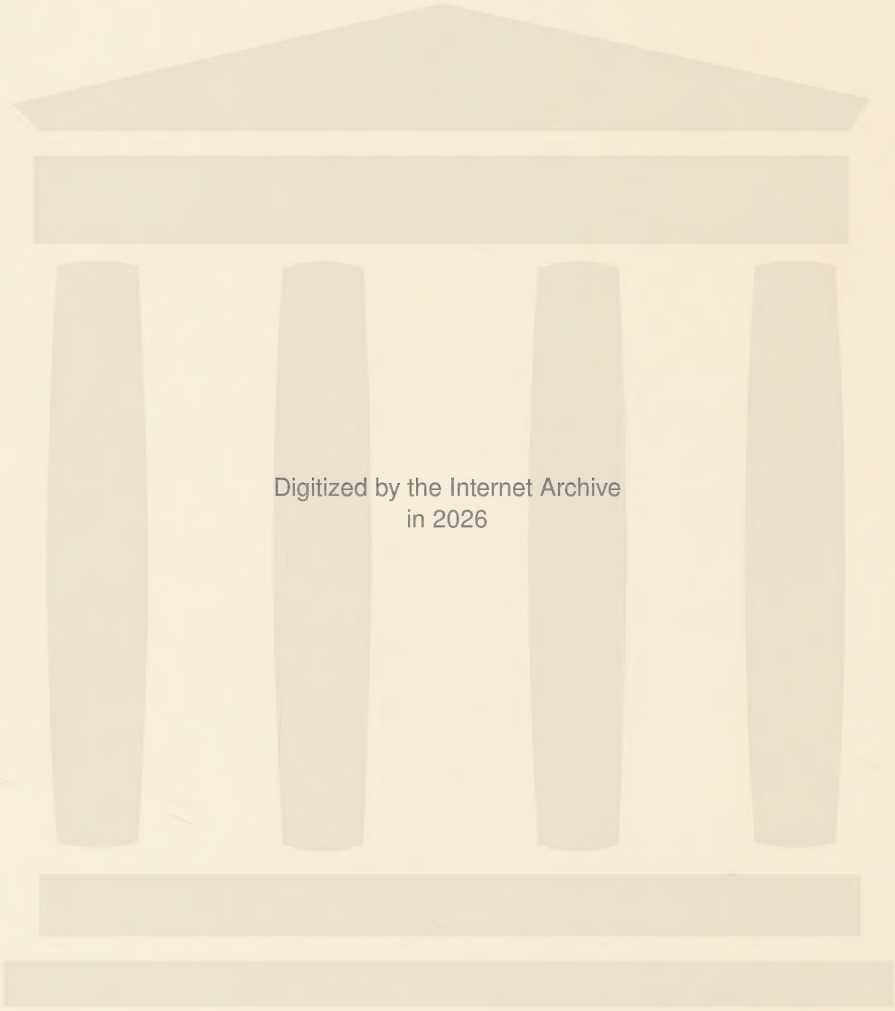
PACIFIC SCIENCE ASSOCIATION

1957

VOLUME 16
OCEANOGRAPHY

Published by the
SECRETARIAT, NINTH PACIFIC SCIENCE CONGRESS
DEPARTMENT OF SCIENCE
BANGKOK, THAILAND
1958


Pacific Science Congress. Proceed.
9th
1957
V.16
BORROWER'S NAME
12-3-60 R. Brown
1-21-63 " "
Pacific Science Congress
Proceedings
9th
1957
V.16
LIBRARY
BUR. OF COMM. FISH.
HON. BIOL. LAB.


Digitized by the Internet Archive
in 2026

https://archive.org/details/proceedings-of-the-ninth-pacific-science-congress-of-the_1957_16

PROCEEDINGS
of the
NINTH PACIFIC SCIENCE CONGRESS
of the
PACIFIC SCIENCE ASSOCIATION

Held at Chulalongkorn University
Bangkok, Thailand
November 18th to December 9th, 1957

Under the auspices
of
HIS MAJESTY'S GOVERNMENT OF THAILAND
and
THE SCIENCE SOCIETY OF THAILAND

VOLUME 16
OCEANOGRAPHY

Published by the

SECRETARIAT, NINTH PACIFIC SCIENCE CONGRESS

DEPARTMENT OF SCIENCE
BANGKOK, THAILAND

1958

Periodical
Pacific Sci. Congress
Proceed.
9th
1957
V.16
2402 co

PUBLICATION COMMITTEE
and
EDITORIAL STAFF

Chairman: DR. CHARNG RATANARAT
Vice-Chairman: M. R. CHAKRATONG TONGYAI
MR. WELLINGTON BRINK PROF. NOPAKHUN TONGYAI
MR. D. V. SASSOON MRS. CATHERINE F. SIFFIN
MRS. M. ISABELLE FARRAR, *Secretary*

PRINTED AT THAI WATANA PANICH (R.O.P.), RAMA I ROAD, BANGKOK. BOONPRING T. SUWAN, PRINTER. B.E. 2501.

CONTENTS

Editor's Note i

Abbreviations ii

Participants iii

Standing Committee Reports

ROCHFORD, D.J. and POWELL, A.W.B., Report of the Chairman of the standing Committee on Pacific Oceanography 1

TULLY, JOHN P., Canadian Pacific Oceanography since 1953 6

SCAGEL, ROBERT F., Report of the Institute of Oceanography, University of British Columbia. . 14

PACIFIC NAVAL LABORATORY, Report on Physical Oceanography—Pacific Naval Laboratory, 1954-57 16

BANNER, A. H., Report of the Hawaii Marine Laboratory 17

GODFREY, MARY LYNNE, Review of POFI's Oceanographic Program, January 1952-June 1957. . 18

WYRTKI, KLAUS, Physical Oceanography in Indonesia, 1954-1957 21

HIDAKA, KOJI and YOSHIDA, KOZO, Physical Oceanography in Japan in the Period 1954-57. . . . 22

BUGNICOURT, F., Note on the Activities of the Oceanographic Section of the Institut Français d'Océanie, 1953-1957 36

BRODIE, J.W., New Zealand Oceanography since 1952 37

SCHWEIGGER, ERWIN, Report on Peruvian Oceanography 39

MEGIA, TEODORO G., Oceanographic Work in the Philippines 40

KOW, THAM AH, Report of the Fisheries Division, Singapore 41

ROYCE, WILLIAM F., Tuna Commission Activities in Pacific Oceanography 42

MILLER, ROBERT C., Report of the California Academy of Sciences, 1951-1957 44

EMERY, K.O., Report of the Allan Hancock Foundation, University of Southern California. . . 45

AHLSTROM, ELBERT H., Research Being Done by the California Cooperative Oceanic Fisheries Investigations on Oceanographic Activities in the Pacific 47

PINKAS, LEO, Report on Oceanographic Activities of the Marine Fisheries Branch of the Department of Fish and Game of the State of California 49

BOLIN, ROLF L., Report of Oceanographic Activities of the Hopkins Marine Station, 1953-1957. . 50

JOHNSON, MARTIN W., Report of the Scripps Institution of Oceanography, 1953-57 51

BURT, WAYNE V., Activities in Oceanography at Oregon State College 57

PIERCE, CHARLES, Report of U.S. Coast and Geodetic Survey 59

Symposium on Marine Upwelling — Physical and Chemical Aspects

HIDAKA, KOJI, Upwelling in a Baroclinic Ocean *(Abstract)* 60

WYRTKI, KLAUS, The Water Exchange between the Pacific and the Indian Oceans in Relation to Upwelling Processes 61

AUSTIN, THOMAS S. and RINKEL, MURICE O., Variations in Upwelling in the Equatorial Pacific . . 67

CROMWELL, TOWNSEND, Thermocline Topography, Horizontal Currents and "Ridging" in the Eastern Tropical Pacific *(Abstract)* 72

YOSHIDA, KOZO, A Study on Upwelling 73

SCHAEFER, MILNER S., BISHOP, YVONNE M. M., and HOWARD GERALD, V., Some Aspects of Upwelling in the Gulf of Panama *(Abstract)* 77

DEACON, G.E.R., Upwelling in the Peru and Genguela Currents *(Abstract)* 78

SCHWEIGGER, E., Upwelling along the Coast of Peru *(Abstract)* 79

LAFOND, E. C., Upwelling in the Bay of Bengal *(Abstract)* 80

Symposium on Marine Upwelling — Biological Aspects

BRANDHORST, WILHELM, Thermocline Topography, Zooplankton Standing Crop and Mechanisms of Fertilization in the Eastern Tropical Pacific *(Abstract)* 81

MCGARY, JAMES W., JONES, EVERET C., and GRAHAM, JOSEPH J., Enrichment in the Transition Zone between the Subarctic and Central Water Masses of the Central North Pacific 82

ARRHENIUS, GUSTAF O.S., Climatic Records on the Ocean Floor *(Discussion)* 90

UDA, MICHITAKA, Enrichment Patterns Resulting from Eddy Systems 91

DOTY, MAXWELL S. and OGURI, MIKIHIKO, Primary Productivity Patterns in Enriched Areas . . . 94

KING, JOSEPH E., Variations in Abundance of Zooplankton and Forage Organisms in the Central Pacific in Respect to the Equatorial Upwelling 98

MURPHY, GARTH I. and SHOMURA, RICHARD S., Variations in Yellowfin Abundance in the Central Equatorial Pacific 108

Symposium on Oceanography and Marine Resources of the Gulf of Thailand

PENYAPOL, A., Report on Oceanographic Surveys Carried out in the Gulf of Thailand during the Years 1956-1957 114

HARRY-ROFEN, R.R. and FEHLMANN, H. ADAIR, Preliminary Results of a Pre-Congress Biological Survey in the Gulf of Thailand *(Discussion)* 124

PENYAPOL, A., Salinity and Temperature Variations of the Surface Water in the Upper Part of the Gulf of Thailand *(Abstract)* 125

PUKASAB, PINICH and POCHANASOMBURANA, PRAVEJ, The Types of Tides and Mean Sea Level in the Gulf of Thailand. 126

CHARERNPHOL, SWARNG, Preliminary Study of Discoloration of Sea Water in the Gulf of Thailand. 131

MA, TING YING H., The Effects of the Warm and Cold Currents in the Southwest Pacific on the Growth Rate of Reef Corals *(Abstract)*. 135

PENYAPOL, A., A Preliminary Study of the Sea Turtles in the Gulf of Thailand *(Abstract)* . . . 136

HENDRICKSON, JOHN R. and ALFRED, ERIC R., Nesting Populations of Sea Turtles on the East Coast of Malaya *(Abstract)*. 137

Symposium on Disposal of Radioactive Wastes

MIYAKE, Y. and SUGIURA, Y., A Method of Measurement of Radioactivity in Sea Water. 139

HIYAMA, YOSHIO and ICHIKAWA, RYUSHI, A Measure on Level of Strontium-90 Concentration in Sea Water around Japan, at the End of 1956. 141

BOROUGHS, HOWARD, The Metabolism of Radiostrontium by Marine Fishes 146

FAUGHN, J.L., FOLSOM, T.R., ISAACS, J.D., JENNINGS, F.D., MARTIN, DEC. JR., MILLER, L.E., and WISNER, R.L., A Preliminary Radioactivity Survey along the California Coast through Disposal Areas. 152

TOMIYAMA, TETUO and KOBAYASHI, KUNIO, Direct Uptake of Radioisotopes by Fish. 159

MARTIN, DECOURCEY, JR., The Uptake of Radioactive Wastes by Benthic Organisms. 167

FOLSOM, THEODORE R., Approximate Dosages Close to Submerged Radioactive Layers of Biological Interest. 170

FOLSOM, THEODORE R., Comparison of Radioactive Dosage from Potassium with Estimated Dosages from Uranium and Radium in Marine Biospheres. 176

Symposium on Physical and Chemical Oceanography

WYRTKI, KLAUS, Precipitation, Evaporation, and Energy Exchange at the Surface of the Southeast Asian Waters *(Abstract)*. 179

DODIMEAD, A.J. and TULLY, J.P., Canadian Oceanographic Research in the Northeast Pacific Ocean. 180

BARBER, F.G., Currents and Water Structure in Queen Charlotte Sound, British Columbia. 196

SUGAWARA, KEN and TERADA, KIKUO, Iodine Distribution in the Western Pacific Ocean *(Abstract)*. 200

KOLESNIKOV, A.G., On the Calculation of Daily Variations of Sea Temperature *(Abstract)*. . . 201

BEZRUKOV, P.L., Sediments of the Trenches in the Northwestern Pacific. 204

Symposium on Biological Oceanography

ZENKEVITCH, L.A., Investigations of Bottom Fauna of the Far Eastern Seas and Adjacent Part of the Pacific *(Abstract)* 208

ZENKEVITCH, L.A., Study of Abyssal Bottom Fauna in the Northwest Part of the Pacific by "*Vitiaz*" *(Abstract)* 209

USHAKOV, P.V., Investigations of the Bottom Fauna of the Far Eastern Seas of the USSR. 210

SEMINA, H.J., The Dependence of the Amount of Phytoplankton upon the Vertical Stability of the Surface Layers in the Boreal Region of the Pacific *(Abstract)*. 217

BEKLEMISHEV, C.W., The Interrelations between Phyto- and Zoo-Plankton in the Bering and Okhotsk Seas *(Abstract)*. 218

BOGOROV, B.G., Biogeographical Peculiarities of the Pelagial of the Northwestern Pacific *(Abstract)*. 219

RASS, TH. S., On the Endemism of the Abyssal Oceanic Ichthyofauna of the North Pacific *(Abstract)*. 220

Symposium on EQUAPAC

TESTER, A.L., Introduction. 221

SUDA, K. and HIKOSAKA, SHIGEO, General Report of Japanese Participation in "EQUAPAC" . . 222

UDA, MICHITAKA, Distribution of Water Masses in the Surface Layer of the Equatorial Pacific *(Abstract)*. 224

HIDAKA, KOJI, Surface Dynamical Topography over 1000-DB Surface Derived from the Result of the "Operation Equapac" in the Summer 1956 *(Abstract)*. 226

MIYAKE, Y., The Distribution of Artificial Radioactivity in the Equatorial Region in the Pacific in the Summer of 1956 *(Abstract)*. 227

KNAUSS, JOHN A., The Equatorial Countercurrent as Shown by the EQUAPAC Observations. 228

Symposium on Techniques of Oceanic Productivity

DOTY, MAXWELL S., A Recent Symposium on "Measurements of Primary Production in the Sea". 233

HIYAMA, YOSHIO and YASUDA, FUJIO, An Analysis on the Production of Plankton-feeders in Offshore Area of Japan *(Abstract)*. 235

HEINRICH, A.K., On the Production of Copepods in the Bering Sea *(Abstract)*. 236

TYLER, JOHN E., Measurement of Light in the Sea. 237

CLARKE, GEORGE L., The Measurement of Bioluminescence in the Sea. 239

EDITOR'S NOTE

At the meeting of the Committee on Publications of the Ninth Pacific Science Congress, it was agreed that the increasing number of communications and papers presented at each Congress has become a very difficult problem for the Publication Committee and the editorial staff to cope with and that too much time is required to complete the publication of the Proceedings; therefore, it was recommended that the following principles governing publication be followed:

a. That invited contributions to the scheduled symposium be published in full;

b. That reports of the Standing Committees be published in full;

c. That other papers submitted to the Congress during its sessions be published in abstract only, the abstract not to exceed 500 words;

d. That papers which, though listed on the program or included in the pre-Congress abstracts published in advance but not actually submitted to the Congress at its sessions, should be disregarded;

e. That authors be asked to indicate by a definite and early date[1] whether they prefer to publish their papers in sources other than the Congress Proceedings; that if this is done, the Congress should be acknowledged;

f. That all proof reading be the responsibility of the editorial committee, and that this committee shall consider the manuscripts in their hands by a definite date as final;[2]

g. That authors be held responsible for submitting their material in good English;

h. That on matters arising during the course of publication and not specifically covered in the statement of policy the editorial committee is empowered to act.

In accordance with the resolutions of the Committee, the editorial board has edited the reports and manuscripts where necessary to bring uniformity and consistency to the format. Typographical and grammatical errors as well as errors in phraseology, spelling, or technical terms have been corrected, wherever possible, but in cases where the exact meaning of the original copy was not clear, the text has been left as submitted by the author.

In order to reduce the cost and bulk of the publication, appendices, illustrations, and exhibits whenever considered not vital to the text have been eliminated.

If an author requested to publish elsewhere, his paper has been mentioned in the footnote under the respective titles, but if an author who presented a paper at the Congress failed to submit his manuscript either in full or in abstract, his paper and the discussions thereon have been eliminated entirely.

It was also decided that, in order to complete the publication of the Proceedings as soon as possible, each division be published in a separate volume. Short volumes or the ones that do not require too much editorial work will be released first. Therefore, among the twenty volumes planned, any volume may appear first. They will not appear in consecutive order.

The editorial board wishes to thank all authors who were prompt in submitting their revised manuscripts in good form and, in particular, members of the Standing and Organizing Committees, too numerous to be named, who have helped in collecting the manuscripts pertaining to their respective divisions.

The Board wishes in particular to thank Dr. F. Raymond Fosberg for going over and correcting the Special Symposium on *Climate, Vegetation, and Rational Land Utilization in the Humid Tropics* under Unesco;

Mr. Saman Buravas of the Royal Mines Department for helping by redrawing charts and maps in order that they might reproduce clearly when printed:

Mr. J. Alan Tubb of the FAO Regional Office, for his assistance in going over and clarifying some of the papers in the Fisheries and Oceanography volumes and in translating some of the French papers;

[1] January 1, 1958, in the case of the Ninth Congress.
[2] March 1, 1958, in the case of the Ninth Congress.

Dr. Pradisth Cheosakul of the Department of Science for editing the Chemistry in the Development of Natural Resources volume;

Last but not least, the Board wishes to thank the *Thai Watana Panich Press* for their cooperative efforts, far beyond the requirement of the contract, in devoting all their resources to printing these volumes.

ABBREVIATIONS

APFC	— Asia-Pacific Forestry Commission
CAA	— Civil Air Administration
CSIRO	— Commonwealth Scientific and Industrial Research Organization (Australia)
ECAFE	— Economic Commission for Asia and the Far East
EQUAPAC	— Equatorial Pacific (oceanographic survey)
FAO	— Food and Agriculture Organization
IACOMS	— International Advisory Committee on Marine Sciences
ICA	— International Cooperation Adminitration
ICAO	— International Civil Aviation Organization
ICSU	— International Council of Scientific Unions
IGY	— International Geophysical Year
IPFC	— Indo-Pacific Fishery Commission
IRC	— International Rice Commission (FAO)
JCRR	— Joint Commission on Rural Reconstruction (Taiwan, China)
NORPAC	— North Pacific (oceanographic survey)
PHILCUSA	— Philippine Council for United States Aid
PIOSA	— Pan-Indian Ocean Scientific Association
SEATO	— South-East Asia Treaty Organization
SPC	— South Pacific Commission
UN	— United Nations
UNESCO	— United Nations Educational, Scientific and Cultural Organization
UNICEF	— United Nations International Children's Emergency Fund
USDA	— United States Department of Agriculture
USIS	— United States Information Service
USOM	— United States of America Operations Mission
WHO	— World Health Organization
WMO	— World Meteorology Organization

PARTICIPANTS †

AKSHARANUGRAHA, LT. COMMANDER SOM, Hydrographic Department, Royal Thai Navy, Thonburi, Thailand.

ALFRED, ERIC RONALD, Zoologist, Raffles Museum, Singapore.

AMATAYAKUL, CHERTCHAI, Investigation Section, Department of Fisheries, Ministry of Agriculture, Rajdamnoen Avenue, Bangkok, Thailand.

BAL, DATTATRAYA VAMAN, Director, The Institute of Science, Mayo Road, Bombay 1, India.

BAMRAJARINPAI, TUANTHAI, Chief, Division of Investigation and Research, Department of Fisheries, Ministry of Agriculture, Rajdamnoen Avenue, Bangkok, Thailand.

BHODHIPHALA, COMMANDER PRAPAT, Hydrographic Department, Royal Thai Navy, Thonburi, Thailand.

BLINKS, LAWRENCE R., Professor of Biology, Stanford University, Hopkins Marine Station, Pacific Grove, California, U.S.A.

BLUMENSTOCK, DAVID I., United States Weather Bureau, P.O. Box 3650, Honolulu, Hawaii.

BOLIN, ROLF L., Professor of Zoology, Stanford University, Hopkins Marine Station, Pacific Grove, California, U.S.A.

BRITTAN, MARTIN R., Associate Professor of Life Sciences, Sacramento State College, Sacramento, California, U.S.A.

BROMHALL, JOHN DEREK, Chief Scientific Officer, Fisheries Research Unit, University of Hong Kong, Hong Kong.

BRONGERSMA, LEO DANIEL, Lecturer, Rijksmuseum van Natuurlijke Historie, Leiden, Netherlands.

BRUUN, ANTON F., Lecturer in Oceanology, University of Zoological Museum, Copenhagen K, Denmark.

BULLARD, EDWARD CRISP, Physicist, Department of Geophysics, Madingly Rise, Madingly Road, Cambridge, England.

CHANSUVAN, COMMANDER SOMCHAI, Head, Marine Security Division, Hydrographic Department, Royal Thai Navy, Thonburi, Thailand.

CHARERNPHOL, LT. COMMANDER SWARNG, Hydrographic Department, Royal Thai Navy, Thonburi, Thailand.

CHIN VIT, COMMODORE CHUN, Hydrographic Department, Royal Thai Navy, Thonburi, Thailand.

CLARKE, GEORGE L., Associate Professor of Zoology, Harvard University and Woods Hole Oceanographic Institution, Cambridge, Massachusetts, U.S.A.

CROMWELL, TOWNSEND,[1] Senior Scientist, Inter-American Tropical Tuna Commission, Scripps Institution of Oceanography, La Jolla, California, U.S.A.

DEACON, GEORGE E. R., Director, National Institute of Oceanography, Wormley near Godalming, Surrey, England.

DESAKORN, REAR ADMIRAL VICHARN, Director, Hydrographic Department, Royal Thai Navy, Thonburi, Thailand.

DEVAHASTIN, LIEUTENANT CHARLIE, Chief of Bio-Oceanographic Section, Hydrographic Department, Royal Thai Navy, Thonburi, Thailand.

DHAMRONGRAT, SAMRAN, Extension Service Section, Division of Inland Fisheries, Department of Fisheries, Ministry of Agriculture, Rajdamnoen Avenue, Bangkok, Thailand.

† Initials or names in italics represent Thai titles.
[1] Deceased.

DOTY, MAXWELL S., Professor of Botany, University of Hawaii, Honolulu 14, Hawaii.

EMERY, K.O., Professor of Geology, University of Southern California, Los Angeles, California, U.S.A.

FYRIES, MARC-MARIE, Chef, Service Océanographic Physique Outre-Mer, 47 Blvd. des Invalides, Paris, France.

FEHLMANN, HERMAN ADAIR, Assistant Curator, George Vanderbilt Foundation, Natural History Museum, Stanford University, Stanford, California, U.S.A.

FOLSOM, THEODORE ROBERT, Senior Engineer, Scripps Institution of Oceanography, University of California, La Jolla, California, U.S.A.

GASKELL, THOMAS F., Chief Physicist, Exploration Department, British Petroleum Comapny Ltd., Britannic House, Finsbury Circus, London, E.C.2, England.

GURJANOVA, EUPRAXIE, Head, Laboratory of the Zoological Institute, Academy of Sciences of the USSR, Leningrad, USSR.

HALSTEAD, BRUCE W., Biotoxicologist, U.S. Naval Medical School, Bethesda, Maryland, U.S.A.

HAMILTON, EDWIN L., Supervisor, Sea-Floor Studies Section, U.S. Navy Electronics Laboratory, San Diego 52, California, U.S.A.

HARDY, ALISTER CLAVERING, Professor of Zoology, Department of Zoology and Comparative Anatomy, University Museum, Oxford, England.

HARRY-ROFEN, ROBERT REES, Research Director, George Vanderbilt Foundation, Natural History Museum, Stanford University, Standford, California, U.S.A.

HIATT, ROBERT W., Dean of the Graduate School and Director of Research, University of Hawaii, Honolulu 14, Hawaii.

HIDAKA, KOJI, Professor, Geophysical Institute, University of Tokyo, Tokyo, Japan.

HIYAMA, YOSHIO, Professor, Fisheries Institute, Faculty of Agriculture, University of Tokyo, Tokyo Japan.

HÖRSTADIUS, SVEN, Professor of Zoology, Zoological Institute, University of Uppsala, Uppsala, Sweden.

HOTRABHAVANON, COMMANDER NOP, Chief, Hydrographic Department, Royal Thai Navy, Thonburi, Thailand.

INDASAURA, SENIOR LIEUTENANT KAMPOL, Meteorological Department, Royal Thai Navy, Bangkapi, Bangkok, Thailand.

INDRAMBARYA, BOON, Director-General, Department of Fisheries, Ministry of Agriculture, Rajdamnoen Avenue, Bangkok, Thailand.

KARNASUT, PRIDA, Chief, Inland Fisheries Division, Department of Fisheries, Ministry of Agriculture, Rajdamnoen Avenue, Bangkok, Thailand.

KHAN, M. R., Assistant Fisheries Officer, FAO Regional Office for Asia and the Far East, Bangkok, Thailand.

KOLESNIKOV, ARKADY, Head, Seathermic Laboratory, Marine Hydrographical Institute, Academy of Sciences of the USSR, Moscow, USSR.

LINDSEY, CASIMIR CHARLES, Assistant Professor, Institute of Fisheries, University of British Columbia, Vancouver 8, B.C., Canada.

LIPIKORN, PAIROJANA, Head, Bangkhen Fisheries Station, Department of Fisheries, Ministry of Agriculture, Bangkhen, Bangkok, Thailand.

MA, TING YING H., Professor, Department of Geology, National Taiwan University, Taipei, Taiwan, Republic of China.

MAHAGITA, COMMODORE SNIT, Deputy Director, Hydrographic Department, Royal Thai Navy, Thonburi, Thailand.

MARR, JOHN CASSIDY, Chief, South Pacific Fishery Investigations, U.S. Fish and Wildlife Service, P.O. Box 271, La Jolla, California, U.S.A.

MARTIN, DECOURCEY, JR., Research Chemist, Scripps Institution of Oceanography, University of California, La Jolla, California, U.S.A.

MATTSSON, LENNART, Director, Unesco, Science Cooperation Office for Southeast Asia, Djl. Diponegoro 76, Djakarta, Indonesia.

MAYO, DONALD SHERWOOD, Agricultural Extension Editor, Agricultural Extension Service, University of Hawaii, Honolulu 14, Hawaii.

MEINKOTH, NORMAN A., Fulbright Foundation Lecturer, Department of Biology, Chulalongkorn University, Bangkok, Thailand.[2]

MILLER, ROBERT C., Director, California Academy of Sciences, San Francisco 18, California, U.S.A.

MILLOT, JACQUES, Directeur, Recherche Scientifique, P.O. Box 434, Tananarive, Madagascar.

MIYAKE, YASUO, Professor of Geochemistry, Meteorological Research Institute, Mabashi, Suginami, Tokyo, Japan.

MOISEEV, PETR, Vice-Director, All-Union Institute of Fishery and Oceanography, Verchnekrasnoselskaya 17, Moscow, USSR.

NEAVE, FERRIS, Principal Scientist, Fisheries Research Board of Canada, Biological Station, Nanaimo B.C., Canada.

PENYAPOL, COMMANDER AMPORN, Chief, Oceanographic Division, Hydrographic Department, Royal Thai Navy, Thonburi, Thailand.

POCHANASOMBURANA, SUB-LIEUTENANT PRAVEJ, Hydrographic Department, Royal Thai Navy, Thonburi, Thailand.

PUKASAB, LT. COMMANDER PINICH, Hydrographic Department, Royal Thai Navy, Thonburi, Thailand.

RAMDAS, L. A., Head, Division of Heat and Power, National Physical Laboratory, Hillside Road, New Delhi 12, India.

REVELLE, ROGER, Director, Scripps Institution of Oceanography, University of California, La Jolla, California, U.S.A.

RIVERO, LUIS HOWELL, Professor, University of Havana, Calle 30 No. 663, Nuevo Vedado, Havana, Cuba.

ROCHFORD, DAVID JAMES, Principal Research Officer, Division of Fisheries and Oceanography, C.S.I.R.O., Sydney, N.S.W., Australia.

RUAMRAGSA, SANAN, Chief, Fish Section, Department of Fisheries, Ministry of Agriculture, Rajdamnoen Avenue, Bangkok, Thailand.

RYTHER, JOHN HOOD, Marine Biologist, Woods Hole Oceanographic Institution, Woods Hole, Massachusetts, U.S.A.

SACHET, MARIE-HELENE, Bibliographer, Pacific Science Board, National Research Council, 2101 Constitution Avenue, Washington 25, D.C., U.S.A.

ST.-AMAND, PIERRE, Head, Optics Branch, Research Department, Michelson Laboratory, Code 5018, U.S. Naval Ordnance Test Station China Lake, California, U.S.A.

SARINDU, LT. COMMANDER VIRAT, Hydrographic Department, Royal Thai Navy, Thonburi, Thailand.

[2] Department of Biology, Swarthmore College, Swartmore, Pennsylvania, U.S.A.

SCAGEL, ROBERT FRANCIS, Associate Professor, Department of Biology and Botany, and Institute of Oceanography, University of British Columbia, Vancouver 8, B.C., Canada.

SEARLE, ANTONY GILBERT, Lecturer in Zoology, Department of Zoology, University of Malaya, Cluny Road, Singapore 10.

SHEPARD, FRANCIS PARKER, Professor, Scripps Institution of Oceanography, University of California, La Jolla, California, U.S.A.

SIDTHIMUNKA, ARIYA, Assistant Chief, Inland Fisheries Division, Department of Fisheries, Ministry of Agriculture, Rajdamnoen Avenue, Bangkok, Thailand.

SILVA, PAUL CLAUDE, Associate Professor, Department of Botany, University of Illinois, Urbana, Illinois, U.S.A.

SIMPSON, ROBERT H., Director, National Hurricane Research Project, P.O. Box 271, West Palm Beach, Florida, U.S.A.

SINHASENI, SUB-LIEUTENANT PRAPAS, Hydrographic Department, Royal Thai Navy, Thonburi, Thailand.

SOONG, MIN KONG, Acting Director, Department of Fisheries, Penang, Federation of Malaya.

SPILHAUS, ATHELSTAN FREDERICK, Dean, Institute of Technology, University of Minnesota, Minneapolis, Minnesota, U.S.A.

SURIYONG, *M.C.* KOSOL, Fisheries Technical Laboratory, Department of Fisheries, Ministry of Agriculture, Rajdamnoen Avenue, Bangkok, Thailand.

SVETSERANI, SAMRONG, Department of Fisheries, Ministry of Agriculture, Rajdamnoen Avenue, Bangkok, Thailand.

SWINGLE, HOMER SCOTT, Professor, Alabama Polytechnic Institute, Fisheries Bldg., Auburn, Alabama, U.S.A.

TESTER, ALBERT LEWIS, Chief, Division of Biological Research, Bureau of Commercial Fisheries, U.S. Fish and Wildlife Service, Department of Interior, Washington 25, D.C., U.S.A.

THAM, AH KOW, Chief Fisheries Officer, Department of Fisheries, Singapore.

THANH, NGO BA, Directeur, l'Institut Océanographique, Nhatrang, Vietnam.

THIEMMEDH, JINDA, Technical Fisheries Officer, Department of Fisheries, Ministry of Agriculture, Rajdamnoen Avenue, Bangkok, Thailand.

THIEMMEDH, SAWASDI, Chief, Administration Division, Department of Fisheries, Ministry of Agriculture, Rajdamnoen Avenue, Bangkok, Thailand.

THIM UDOM, CAPTAIN SAWAN, Hydrographic Department, Royal Thai Navy, Thonburi, Thailand.

THOMPSON, WARREN CHARLES, Associate Professor of Oceanography and Aerology, Department of Aerology, U.S. Naval Postgraduate School, Monterey, California, U.S.A.

TOMIYAMA, TETUO, Professor, Kyushu University, Hakozaki-machi, Fukuoka, Japan.

TONGKUMWONG, COMMANDER SOPON, Chief, Hydrographic Survey Division, Hydrographic Department, Royal Thai Navy, Thonburi, Thailand.

TONGSANGA, SANITH, Bangkhen Fisheries Station, Department of Fisheries, Ministry of Agriculture, Bangkhen, Bangkok, Thailand.

TRINH, NGUYEN QUANG, Recteur, Université de Saigon, Saigon, Vietnam.

TUBB, JOHN ALAN, Regional Fisheries Officer, FAO Regional Office for Asia and the Far East, Bangkok, Thailand.

TUCKER, ALLAN, Professor and Science Consultant, Michigan State University Mission to University of the Ryukyus, Okinawa, USCAR-Educ., APO 331, San Francisco, California, U.S.A.

TYLER, JOHN E., Research Physicist, Scripps Institution of Oceanography, University of California, La Jolla, California, U.S.A.

USCHAKOV, PAVEL, Professor, Zoological Institute, Academy of Sciences of the USSR, Leningrad 164, USSR.

VARIKUL, VANICH, Investigation Section, Department of Fisheries, Ministry of Agriculture, Rajdamnoen Avenue, Bangkok, Thailand.

WYRTKI, KLAUS, Head, Institute of Marine Research, Djakarta, Indonesia.[3]

YOSHIDA, MASAO, Natural Sciences Department, c/o UNESCO, 19, Avenue Kleber, Paris XVI[e], France.

[3] C.S.I.R.O. Marine Laboratory, Box 21, Cornulla, Sydney, N.S.W., Australia.

OCEANOGRAPHY

Standing Committee Chairman: D.J. ROCHFORD
Standing Committee Secretary: A.W.B. POWELL
Organizing Committee Chairman: SANITH MAHAGITA

Standing Committee Report

REPORT OF THE CHAIRMAN OF THE STANDING COMMITTEE ON PACIFIC OCEANOGRAPHY

D. J. ROCHFORD

Division of Fisheries and Oceanography, C.S.I.R.O., Sydney, N.S.W., Australia.

and

A.W.B. POWELL

Auckland Institute and Museum, Auckland, New Zealand.

INTRODUCTION

At each Congress, it is customary for the Chairman to present a report on the progress of Pacific oceanography since the previous Congress, to draw your attention to advances and recessions in its study, to summarize the national reports, and suggest matters for the members and the Recommendation Committee to consider in some detail.

The Secretary and I have been almost entirely dependent upon correspondence and exchange of published reports and papers for the preparation of this report, and there are probably large gaps and omissions in it because of this.

In respect of disciplines, there is a lack of national reports on biological oceanography, although to a certain extent this may be covered in the reports to the Standing Committee on Fisheries. There is no national report from the U.S.S.R. as this country, which was not represented at the last Congress on Oceanography, has no nominee on the Standing Committee. It is evident, of course, from their active participation in this Congress, and the number of major Russian oceanographical voyages in the Pacific Ocean in recent years, that this defect must be remedied in the future.

With the growth of oceanographical science in the Pacific in recent years it is becoming increasingly difficult for the Standing Committee to keep abreast of developments between Congresses. This problem becomes more acute if the Chairman and Secretary are from countries of relatively low oceanographical standing and isolated geographically from the major centres of research. Admittedly the major purpose of the Standing Committee is to aid the organization of symposia and business sessions at the following Congress, but it also is required to aid the implementation of the recommendations of the previous Congress. The Standing Committee must therefore have some degree of executive as well as advisory function. Because of necessity, however, it must have a limited membership covering only most disciplines and geographical regions.

At the previous Congress the retiring Chairman, Dr. T. G. Thompson, recommended to the Oceanography Division that an Oceanographical Society of the Pacific would provide an answer to these problems. Such a society would have an executive committee which would function for the Association in much the same manner as the present standing committee, but it would have a much more representative membership of all oceanographers. It should there-

fore be of greater inspiration to the younger scientists and act as a catalyst for the stimulation of marine research. Little, however, has been done towards the active establishment of such a society, and this Division should consider its desirability and frame definite recommendations about its objectives and membership, if necessary. Unesco might be approached to provide assistance for the secretarial and publication costs of such a society.

Since the last Congress, tremendous advances in our knowledge of the descriptive oceanography of the north Pacific Ocean have been made as a result of national but more particularly international expeditions such as Norpac and Equapac. The IGY programme in Pacific oceanography will extend these studies.

In the South Pacific it will require similar international collaboration and exchange of facilities and personnel to study this region since the countries bordering it are very poor in oceanographical resources. Unesco has provided funds for holding regional meetings on marine biology and resources of the sea in Latin American countries. Four such meetings have been held since 1954, two in Chile, one in Brazil, and one in Peru. The last which was held in Lima, Peru, in October, 1956, was attended by oceanographers from U.S.S.R., U.S.A., Mexico, Japan, India, Australia, U.K., Denmark, and France by Unesco scheduling a regional symposium prior to its Iacoms meeting.

Arising out of this meeting, it seems probable that Scripps will devote some time and effort to a study of the oceanography of the southeast Pacific. This will fill in a big gap in our descriptive knowledge of the South Pacific Ocean.

To aid the coordination of oceanographical work in the southwest Pacific, Unesco has made funds available for the organizing of a meeting in Australia in 1958 of oceanographers from New Zealand, New Caledonia, and Australia.

The sponsoring and financing of such meetings are probably the most effective initial steps, but this Division might consider the problem further and develop a more long-term solution.

Since the last Congress, the widespread use of C^{14} method by Japan, Canada, U.S.A. including Hawaii, and recently New Caledonia and Australia, supplemented by surveys of other regions by Professor Doty of Hawaii, has given us a picture of the geographic variation in the rates of carbon fixation for the Pacific Ocean. This is a direct measurement of the fixation rate, compared with the earlier indirect estimates from changes in phosphates and carbon dioxide. This method could be employed by many of the Asian countries with limited oceanographical resources, using merchant ships for collection and for the preliminary shipboard manipulations. The counting and interpretation of the filtered material can be carried out later at regional centres with the necessary electronic equipment. Steemann Nielsen has made a suggestion to Unesco that a number of key laboratories be set up to prepare C^{14} ampoules, filter discs, and other equipment on a large scale to reduce costs and sell them to countries not wishing to employ staff and equipment for this purpose. After use, the filters and the filtered material would then be assayed at the nearest convenient centre. Of course it would be desirable to have the complete interpretation of the results that parallel studies of submarine light and physical and chemical structure of the same waters would provide, but in their absence the method can still provide very direct and useful data.

The routine processing of oceanographical data has received considerable attention at Scripps since the beginning of the Marine Life Project. American, Canadian, and to some extent Japanese oceanographers now appear to accept a reasonably standardized method of processing, plotting, and routine interpretation of their data. Handbooks such as U.S. Hydrographic Office Nos. 607 and 614, and University of Washington Special Report No. 23, containing details of procedures for collection, analysis, and processing of data are now available. Such standardization was essential to the success of international expeditions such as Norpac and Equapac.

Another important advance in Pacific oceanography has been heralded by the publication of *Oceanic Observations of the Pacific* by the Scripps Institution. This is the first published book containing oceanographical data which can be purchased off the shelf anywhere in the world. It therefore represents a major step in the internationalization of Pacific oceanography.

Recently, too, our Japanese colleagues have been publishing more of their papers in English, or failing that, giving an English summary. This represents a considerable effort on their part, but considering the scope and magnitude of their oceanographical effort, it is to be hoped that this tendency will increase.

The Division might seek from the editors of the

Oceanic Observations the cost of publishing data from other countries and how much of this would have to be borne by the country concerned. If the data can be printed with minimum delay and cost, Pacific countries in general might utilize it.

The Japanese and American reports demonstrate the versatility of their oceanographic programs. Your Chairman feels, however, that to some extent material resources in these countries may be greater than the trained manpower to process and interpret field data at a reasonable rate. To some extent this shortage of manpower can be minimized by the use of electronic computers and data storage and handling machines, which reduce considerably the time spent by the researcher on the processing of the data.

Another problem which arises in these oceanographically advanced countries is the overlap and duplication of effort brought about by lack of national coordinating and planning centres. This problem appears most pressing in Japan where oceanography is such a common science that every university and many government departments which would not have an interest in the subject in other countries are very actively engaged in its study.

Unesco recently requested Dr. Hidaka to prepare a long-range plan for the best use of Japanese oceanographers in the elevation of Japanese living standards. His plan, calling for intensive study of the Kuroshio and Inland-Seas, has been accepted by the Japanese Government.

Canada appears to have developed a happy solution to this problem of national coordination with its Joint Committee on Oceanography, which has fostered a balanced programme of research on both the coastal seaways and inlets and oceanic regions of the Pacific seaboard of Canada.

In Australia, the Australian Academy of Science has recently accepted responsibility for coordination of marine research and has set up a Standing Committee on Oceanography. In New Zealand, an Oceanography Committee was formed in 1950 as advising body to the D.S.I.R. In Indonesia, Singapore, the Philippines, and New Caledonia, the oceanographic investigations form part of a general survey of marine resources and are under the direct control of the government department concerned.

In Peru, the Guano Company is interested in oceanography as a means of forecasting trends in the Guano industry and employs an oceanographer and a vessel to survey the coastal waters of Peru.

In Thailand, the Royal Thai Navy has shown increasing interest in oceanography. With a nucleus of trained oceanographers in its Hydrographic Department, there exists a unique opportunity for resolute and efficient prosecution of oceanographical studies in Thai waters. This Division will follow with keen interest the future development of oceanography in Thai waters.

To assist Asian countries in the development and coordination of the research programmes in oceanography, Unesco is considering a proposal to appoint an oceanographer of international repute to visit these countries, familiarize himself with local personnel and facilities, and examine their oceanographical needs and finances available for their implementation.

From such a survey, a statement of future needs in finance, personnel, and equipment to initiate or supplement the most suitable national programmes could be prepared at the request of the individual governments. Unesco help, in the form of technical assistance or aid to member State allocations, might then be sought.

The IPFC of FAO submitted a proposal to Unesco for setting up in the Indo-Pacific region a centre or centres for coordinating and fostering oceanographical work in this area. The International Advisory Committee of Unesco considered this proposal and deferred it because of difficulties in locating, manning, and financing it at the present time. At the last Congress notice was given of a proposed Geophysical Institute for the Central Pacific to be founded in the University of Hawaii. Present advice is that the nucleus of this Institute has already been established, but that future development is dependent upon the extent of U.S. Government support. This will be decided by Congress early in 1958.

Recently, Iacoms considered the feasibility of operating a U.N. oceanographical research vessel which would explore the lesser-known regions of the world, training oceanographers from the neighboring countries, and building up an awareness of the international character of the science, by recruiting scientific staff and crew from all over the world. This matter is still under consideration by Iacoms and Unesco headquarters, but an expression of opinion by the oceanographers of this Division would be welcome.

SUMMARY OF PACIFIC OCEANOGRAPHY 1954-57

It is proposed to make available to all members of this Division full or summary copies of the national reports on Pacific oceanography as soon as possible. The originals will be available in the Divisional Office for any member to use at any time. However, I would like to put before you a tabulated summary of the numbers of institutions in the Pacific which have consistently worked upon various fields of oceanography since 1954.

It has been very difficult to obtain the information for this tabulation, and many errors and omissions may be apparent to you in your own country. Moreover, the range of fields selected is rather limited and may not be acceptable to the members of the Division. However, I feel that if some standard form for circulation to Pacific countries was available, a year-by-year summation of the progress and decline in the various fields could be easily prepared by the Standing Committee. We might even consider that once the standard form was agreed upon, the Unesco Science Cooperation Office in Djakarta might undertake such a compilation for us.

	OCEANOGRAPHICAL SURVEYS					PHYSICS								CHEMISTRY							GEOLOGY				BIOLOGY									GENERAL			
		OCEANIC	DEEP SEA	COASTAL	ESTUARINE		UPWELLING.	LIGHT	SOUND	WAVES-SWELL	THERMAL STRUCTURE	WATER MASSES and CIRCULATION	HYDRODYNAMICS		GEOCHEM. CYCLES	BOTTOM SEDIMENTS	COMP. OF MAR. ORGS.	RADIO CHEM.	BIOCHEMISTRY	PRODUCTIVITY		SUBMARINE FEATURES	BOTTOM SEDIMENTS	STRUCTURE OCEAN FLOOR		GENETICS	POP. DYNAMICS	MICRO. BIOLOGY	PHYT. PLKT.	ZOO. PLKT	BOTANY	INVERTEBRATES	VERTEBRATES.		SEA LEVEL	TIDES	INSTRUMENTS
AUSTRALIA	1		1	1			1	1	1		1			1	1	1			1								1	1	1	1	2	3		2	1	1
CANADA	1	1	1				1		1	1	1	1		1		1			1									1	1							
INDONESIA										1	1																									
JAPAN	8	?	2	1		2	2	1	4		8	2		2	1		1		1		2	1			1									1	1	1
NEW CALEDONIA	1						1				1			1					1									1			1				
NEW ZEALAND	1		1								1										1	1	1			1		1	1	2	1				
PERU	1		1																																	
PHILIPPINES			1											1														1							
SINGAPORE			1											1														1	1			1			
U.S.A.	5	1	1	1		1	2	1	1	1	3	2			1		1	1	3		1	2	1		1	1	1	2	2	1	3	4		1	1	1
TOTALS	18	2	9	3		3	7	3	7	3	16	5		7	3	2	2	1	7		4	4	2		1	2	3	5	8	3	7	10		4	3	3

Number of Institutions working upon above fields in PACIFIC OCEANOGRAPHY, 1954-57.
(Compiled from National Reports available Sept., 1957.)

From a complete and accurate tabulation, the Standing Committee could advise Unesco and the Pacific Science Association Secretariat of needs and deficiencies more realistically than seems possible now. To take an example from the present tabulation, we could draw Unesco's attention to the lack of studies on the structure of the ocean floor and ask the New Zealand and U.S.A. governments to continue their present interest in this subject.

Progress in the development of oceanographical instrumentation is vital to the science, and the Pacific countries in this field should be encouraged to exchange information and have their scientists meet at frequent intervals.

In the biological fields, the tabulation does not indicate whether ecological, physiological, taxonomic, or distribution studies are carried out.

It is probable, for instance, that taxonomic studies of many marine groups are being neglected. It would be desirable, therefore, for the Standing Committee to have such details available so that encouragement can be given to the institution and persons concerned to carry on and efforts made to attract junior scientists into the waning fields of study.

Despite its limitations, therefore, I would like to table this present tabulation so that members can examine and criticize its format and contents. The Division might consider the feasibility of some such standard form for the collection and presentation of these data each year.

In conclusion, Dr. Powell and I wish to thank the members of the Standing Committee for their generous support during our term of office. We wish also to congratulate the local Organizing Committee in Bangkok on their pre-Congress preparations and splendid arrangements for our Divisional meetings.

I would finally like to draw your attention to the necessity of a recommendation from this Division for the continuance of a Standing Committee on the Oceanography of the Pacific, whose Chairman must be nominated by this Division but ratified by the President of the Congress.

The membership and programme of the Standing Committee is determined by this Chairman.

CANADIAN PACIFIC OCEANOGRAPHY SINCE 1953

JOHN P. TULLY

Fisheries Research Board of Canada, Pacific Oceanographic Group, Nanaimo, B.C., Canada.

In Canada, oceanographic research is supported by the Federal Government through the Canadian Joint Committee on Oceanography. This Committee includes representation from the Fisheries Research Board of Canada which provides scientific staff, research equipment, laboratories, and administration at Nanaimo, British Columbia; from the Royal Canadian Navy which provides and operates two full-time ocean-going research vessels on the Pacific coast; the Hydrographic Service which undertakes auxiliary and tidal observations along with hydrographic surveys; the Meteorological Service which provides facilities in the weatherships on ocean weather station PAPA (latitude 50° N., longitude 145° W.); the Defence Research Board of Canada which provides logistic and material support; and the National Research Council of Canada which provides material assistance. The programs are directed toward the immediate and long-term needs of these supporting members of the Joint Committee. Close liaison is maintained with all agencies, domestic and foreign, having an interest in the oceanography of the north Pacific Ocean.

During the years since the last Congress (1953), the Canadian observational and research effort in the Pacific has increased considerably. Studies of the larger coastal seaways and of the northeast Pacific Ocean have been undertaken; and, in addition, fundamental studies in physics and chemistry have been initiated. The use of hydraulic models as an oceanographic tool has continued, and at the present time the tidal features of a large coastal region are being studied through this medium. Computers of various types are being used as aids in processing and interpreting field data and in theoretical problems. A considerable proportion of the effort has been devoted to observations of the properties of the water from surface to 1,500 meters depth, and interpretation of these data to describe the structure, mechanism, and biotic productivity of the waters of interest to Canada.

In the summer of 1955, oceanographic agencies from the United States, Japan, and Canada cooperated in Project Norpac. This was a synoptic survey of the Pacific Ocean north of latitude 20° N. Twenty ships took part and about 1,000 stations were occupied during the month of August. The data were processed, published, and the data records exchanged in Honolulu in February, 1956, five months after completion of the sea work. This was the most comprehensive survey ever undertaken in any oceanic area.

Since Norpac, the stimulus for oceanic study has been provided by the International North Pacific Fisheries Commission. Under this protocol, Canada has carried out extensive exploratory fishing and oceanographic observations through the summers of 1956 and 1957. In support of this work, comprehensive oceanographic surveys have been made in the oceanic area north of latitude 40° N. and east of longitude 170° W., in August, 1956, and in February and August, 1957.

Time series observations are taken from the weathership at ocean weather station PAPA (latitude 50°N., longitude 145° W.) to monitor the changing conditions in mid-ocean. These include semi-daily bathythermograph observations, which are continuous since 1952. In 1956, an oceanographer was placed on one of the two ships which occupy the station for alternate six-week periods. This provides bi-weekly observations of the properties of the water from surface to 1,500 meters depth, and plankton to 300 meters depth.

In conjunction with these oceanic programs, drift bottles, in lots of 1,000, have been released every six weeks from the weathership, and at four positions across the area of each survey. A one dollar reward is paid to the finder for return of the enclosed information card with date and place of recovery. The cards are printed in English, Spanish, Japanish, and Russian.

Detailed surveys are now being carried out in the waters over the continental shelf and slope and for a distance of 200 miles to seaward, five to six times a year. This program provides the description of the continental periphery of the oceanic system and describes the region of active Canadian fisheries. In support of this program, daily observations of surface seawater temperature and salinity are made at four lightstations

along the ocean coast. These provide continuous data necessary to link the intermittent data from the surveys. They are continuous since 1935 and provide a means of evaluating oceanographic conditions in the past as well as in the present.

Oceanographic exploration of the inshore seaways has been completed. The last such project was in the sea area between the Queen Charlotte Islands and the mainland, where surveys were carried out at bi-monthly intervals for nearly two years. Daily seawater observations from lightstations are made at strategic points in all coastal seaways to provide a continuing monitor of the conditions which have been defined by the surveys.

Recently the techniques of seawater analyses and the tedious calculations in the data have been mechanized. Salinity is determined at sea with precision conductivity equipment to a higher degree of accuracy than was previously possible in a shore laboratory with standard chemical apparatus. All computations are carried out by a digital computer. The data can now be published in a manuscript (multilith) series, within one month of the conclusion of sea operations.

Research is being undertaken in the field of biotic productivity. The amount of organic carbon in the plankton is determined as the measure of the standing crop. Carbon fourteen studies are being undertaken to determine the rate of productivity. The nutrient content of the water is being determined by modernized methods. The role and importance of the various nutrients and light in the sea is being undertaken. All these lead to assessment of the fertility in the sea and its controlling factors.

The physical program is being extended to consider the heat exchange between sea and atmosphere to determine the manner and rate of the heating and cooling processes. Studies of abyssal water are being undertaken to determine their source, rate of movement, and mechanics of their entrainment into the surface waters. This research is also of importance to the prediction of pollution from nuclear wastes disposed in the deep ocean.

Hydraulic models have been used successfully to study the tidal and flushing mechanisms of coastal seaways where the boundary conditions are known. These models also assist materially in the appreciation and interpretation of sea data and indicate regions of importance in the area of study. The most recent project is a model of the sea area between the Queen Charlotte Islands and the mainland, to reveal the tidal currents and circulation system, which could not be economically resolved from sea data. The model is 30 meters long by 10 meters wide representing an area of 70,000 square kilometers. It has a highly distorted length to depth ratio. Fresh and sea water are used to reproduce the density gradients. Tides are predicted by an electronic computer and imposed on the model mechanically. The tidal rise at points in the area is recorded and compared to the predicted tides. The tidal currents are observed by photographing the movement of dye patches in the model.

Oceanographic education at the postgraduate level is offered at the Institute of Oceanography of the University of British Columbia at Vancouver, British Columbia. Candidates having a B.A. degree may proceed to a Master's degree in chemistry in the sea, or to a Master's or Doctor's degree in physics or biology in the sea. The facilities provide for two years of lecture courses and opportunities for research and sea experience. Registration has been encouraging, and graduates have been readily placed in responsible positions in oceanographic research.

Data from oceanographic surveys and experimental work are published in a manuscript report series which is circulated to the principal laboratories interested in north Pacific studies. Interim results of continuing research are also published in this series, but conclusive results are published in the *Journal of the Fisheries Research Board of Canada* or in journals suitable to the topic.

The following is a summary of recent oceanographic literature resulting from these studies:

Oceanography of Oceanic Regions

Tully, John P., 1936, Weather and the Ocean. Fish. Res. Bd. Canada, *Prog. Rept. Pac.*, **26**: 5-10.

————, 1936, Ocean Currents. Fish. Res. Bd. Canada, *Prog. Rept. Pac.*, **30**: 16-19.

————, 1937, A Warmer Summer. Fish. Res. Bd. Canada, *Prog. Rept. Pac.* **31**: 16-18.

————, 1937, Gradient Currents. Fish. Res. Bd. Canada, *Prog. Rept. Pac.*, **33**: 13-14.

————, 1937, Why is the Water Along the West Coast of Vancouver Island so Cold? Fish. Res. Bd. Canada, *Prog. Rept. Pac.*, **34**: 13-15.

Tully, John P., 1937, Report on Dynamic Studies off the Canadian Pacific Coast, *Amer. Geophys. Union*, 18th. Annual Meeting, **1937**: 228-321.

————, 1938, Some Relations between Meteorology and Coast Gradient Currents off the Pacific Coast of North America, *Amer. Geophys. Union*, 19th. Annual Meeting, **1938**: 176-183.

————, 1942, Surface Non-Tidal Currents in the Approaches to Juan de Fuca Strait, *J. Fish. Res. Bd. Canada*, **5** (4): 398-409.

Waldie, R.J., Doe, L.A.E., and Associates, 1950, Oceanographic Discovery. Fish. Res. Bd. Canada, *Prog. Rept. Pac.*, **84**: 59-63.

Doe, L.A.E., 1951, Sea-Surface Temperatures, 1950 - 51. Fish. Res. Bd. Canada, *Prog. Rept. Pac.*, **88**: 53-56.

————, 1952, Oceanographic Studies off the Canadian Pacific Coast. Fish. Res. Bd. Canada, Joint Comm. on Oceanogr., *MS Report*, 8 pp.

Tully, John P. and Bennett, E.B., 1952, Project "Offshore." Coastal Temperatures and Tuna. Fish. Res. Bd. Canada, *Prog. Rept. Pac.*, **92**: 6-9.

Tully, John P., 1953, Some Characteristics of Sea Water Structure. Fish. Res. Bd. Canada, Joint Comm. on Oceanogr., *MS Report*, 21 pp.

————and Doe, L.A.E., 1953, Surface Waters off the Canadian Pacific Coast. Fish. Res. Bd. Canada, Joint Comm. on Oceanogr., *MS Report*, 7 pp.

Doe, L.A.E., 1955, Offshore Waters of the Canadian Pacific Coast, *J. Fish. Res. Bd. Canada*, **12** (1): 1-34.

Saur, J.F.T., Tully, J.P. and LaFond, E.C., 1955, Oceanographic Cruise to the Bering and Chukchi Seas, Summer 1949, Part IV. Oceanographic Studies. *U.S.N.E.L. Report No. 416*, **1**, 31 pp.

Dodimead, A.J., 1956, Project Norpac. Fish. Res. Bd. Canada, *Prog. Rept. Pac.*, **105**: 16-18.

Tully, J.P. and Dodimead, A.J., 1956, Pacific Salmon Water? Fish. Res. Bd. Canada, *Prog. Rept. Pac.*, **107**: 28-32.

OCEANOGRAPHY IN COASTAL SEAWAYS AND ESTUARIES

Tully, John P., 1937, Oceanography of Nootka Sound, *J. Biol. Bd. Canada*, **3** (1): 43-69.

Cameron. W.M., 1948, Fresh Water in Chatham Sound. Fish. Res. Bd. Canada, *Prog. Rept. Pac.*, **76**: 72-25.

Tully, John P., 1949, Oceanography and Prediction of Pulp Mill Pollution in Alberni Inlet, *Bull. Fish. Res. Bd. Canada*, **83**: 169 pp.

Waldie, R.J., 1950, Fresh Water in Georgia Strait. Fish. Res. Bd. Canada, *Prog. Rept. Pac.*, **83**: 42-44.

————, 1951, Winter Oceanography of Baynes Sound and the Lazo Bight. Fish. Res. Bd. Canada, Joint Comm. on Oceanogr., *MS Report*, 9 pp.

Cameron, W.M., 1951, On the Transverse Forces in a British Columbia Inlet, *Trans. Roy. Soc. Canada*, **45** (3): 1-8.

Doe, L.A.E., 1952, Currents and Net Transport in Loudoun Channel, *J. Fish. Res. Bd. Canada*, **9** (1): 42-64.

Tully, John P., 1952, Oceanographic Data of the Western Canadian Arctic Region 1935-37, *J. Fish. Res. Bd. Canada*, **8** (5): 378-382.

————, 1952, Notes on Behaviour of Fresh Water Entering the Sea, *Proc. Seventh Pac. Sci. Congr.*, **3**: 23 pp.

Waldichuk, M., 1952, Oceanography of the Georgia: I. Salinity Distribution. Fish. Res. Bd. Canada, *Prog. Rept. Pac.*, **93**: 26-29.

Pickard, G.L., 1953, Oceanography of British Columbia Mainland Inlets: I. Water Characteristics. Fish. Res. Bd. Canada, *Prog. Rept. Pac.*, **96**: 3-6.

————, 1953, Oceanography of British Columbia Mainland Inlets: II. Currents. Fish. Res. Bd. Canada, *Prog. Rept. Pac.*, **97**: 12-13.

Shand, J.A., 1953, Internal Waves in Georgia Strait, *Trans. Amer. Geophys. Union*, **34** (6): 849-856.

Waldichuk, M., 1953, Oceanography of the Strait of Georgia: II. Temperature Distribution. Fish. Res. Bd. Canada, *Prog. Rept. Pac.*, **94**: 19-23.

Waldichuk, M., 1953, Oceanography of the Strait of Georgia: III. Character of the Bottom. Fish. Res. Bd. Canada, *Prog. Rept. Pac.*, **95** : 59-63.

————, 1953, Oceanography of the Strait of Georgia: IV. Dissolved Oxygen Distribution. Fish. Res. Bd. Canada, *Prog. Rept. Pac.*, **96** : 6-10.

Barber, F.G., 1954, Water Masses in Queen Charlotte Strait. Fish. Res. Bd. Canada, *Prog. Rept. Pac.*, **100** : 6-7.

————, and Tabata, S., 1954, The Hecate Oceanographic Project. Fish. Res. Bd. Canada, *Prog. Rept. Pac.*, **101** : 20-22.

Pickard, G.L., 1954, Oceanography of British Columbia Mainland Inlets: III. Internal Waves. Fish. Res. Bd. Canada, *Prog. Rept. Pac.*, **98** : 13-16.

————, 1954, Oceanography of British Columbia Mainland Inlets: IV. Dissolved Oxygen Distribution. Fish. Res. Bd. Canada, *Prog. Rept. Pac.*, **99** : 9-11.

Tabata, S., 1954, The Problem of Sea Water Intrusion in Steveston Cannery Channel. Fish. Res. Bd. Canada, Joint Comm. On Oceanogr., *MS. Report*, 6 pp.

————, 1954, Oceanography of British Columbia Mainland Inlets: V. Salinity and Temperature of Waters in Bute Inlet. Fish. Res. Bd. Canada, *Prog. Rept. Pac.*, **100** : 8-11.

Waldichuk, M. and Barraclough, W.E., 1954, Offshore Characteristics in the Deep Waters of the Strait of Georgia as Indicated by Bathypelagic Fish, *J. Fish. Res. Bd. Canada*, **11**(5) : 501-506.

PACIFIC OCEANOGRAPHIC GROUP OF THE FISHERIES RESEARCH BOARD OF CANADA

Anonymous, 1955, Physical and Chemical Data Record, Hecate Project, with Appendix I, Current Observations, 1955. Fish. Res. Bd. Canada, Joint Comm. on Oceanogr., *MS Report*, 107 pp.

Pickard, G.L., 1955, British Columbia Inlets, *Trans. Amer. Geophys. Union*, **36**(5) : 897-901.

Tabata, S., 1955, Oceanographic Conditions in Steveston Harbour during Normal Discharge of the Fraser River. Fish. Res. Bd. Canada, *Prog. Rept. Pac.*, **104** : 26-29.

Tabata, S. and LeBrasseur, R.J., 1955, Studies in Steveston Harbour Basin: Part I. Sea Water Intrusion in to the Steveston Harbour Basin, by S. Tabata; Part II. Shipworm Infestation at Steveston Harbour Basin, by R.J. LeBrasseur. Fish. Res. Bd. Canada, Joint Comm. on Oceanogr., *MS Report*, 31 pp.

Barber, F.G., 1956, Seasonal Temperature and Salinity Variations in Queen Charlotte Strait, British Columbia. Fish. Res. Bd. Canada, *Prog. Rept. Pac.*, **105** : 14-15.

————, 1956, On the Dissolved Oxygen Content of the Waters of the Hecate Region. Fish. Res. Bd. Canada, *Prog. Rept. Pac.* (submitted for publication).

————, 1956, The Effect of the Prevailing Winds on the Inshore Water Masses of the Hecate Region, British Columbia, *J. Fish. Res. Bd. Canada* (submitted for publication).

Kirsch, Milton., 1956, Ionic Ratios of Some of the Major Components in River-Diluted Sea Water in Bute and Knight Inlets, British Columbia, *J. Fish. Res. Bd. Canada*, **13**(3) : 273-289.

PACIFIC OCEANOGRAPHIC GROUP OF THE FISHERIES RESEARCH BOARD OF CANADA

Anonymous, 1956, Data Record, Fraser River Estuary, Steveston Cannery Basin, August 3, 1954 to October 6, 1955. Fish. Res. Bd. Canada, Joint Comm. on Oceanogr., *MS Report*, 33 pp.

Tabata, S., 1956, Heat Budget of the Water in the Vicinity of Triple Island, British Columbia. Fish. Res. Bd. Canada, Joint Comm. on Oceanogr., *MS Report* 17 pp. Also, *J. Fish. Res. Bd. Canada* (submitted for publication).

————, 1956, Sea Water Intrusion in Steveston Cannery Basin. Fish. Res. Bd. Canada, *Prog. Rept. Pac.*, **106** : 3-6.

————, 1956, Heat Exchange Between Sea and Atmosphere in Northern British Columbia Coast. Fish. Res. Bd. Canada, *Prog. Rept. Pac.* (submitted for publication).

————and LeBrasseur, R.J., 1956, Sea Water Intrusion into the Fraser River and its Relation to the Incidence of Shipworms in Steveston Cannery Basin. Fish. Res. Bd. Canada, Joint Comm. on Oceanogr., *MS Report*, 17 pp.

Trites, R.W., 1956. The Oceanography of Chatham Sound, British Columbia, *J. Fish. Res. Bd. Canada*, **13** (3) : 385-434.

Waldichuk, M., 1956, Oceanography of the Strait of Georgia: VI. Fresh Water Budget. Fish. Res. Bd. Canada, *Prog. Rept. Pac.*, **107** : 24-27.

Tabata, S. and Pickard, G.L., 1957, The Physical Oceanography of Bute Inlet, British Columbia, *J. Fish. Res. Bd. Canada*, **14** (4).

Tully, John P. and Domimead, Allan J., 1957, Properties of the Water in the Strait of Georgia, British Columbia and Influencing Factors, *J. Fish. Res. Bd. Canada*, **14** (3) : 241-319.

Waldichuk, M., 1957, Physical Oceanography of the Strait of Georgia, *J. Fish. Res. Bd. Canada*, **14** (3) : 231-486.

TIME SERIES STUDIES

Tully, John P., 1937, Seasons in the Sea. Fish. Res. Bd. Canada, *Prog. Rept. Pac.*, **32** : 11-12.

Hollister, H.J., 1949, Daily Sea Water Observations in Georgia Strait. Fish. Res. Bd. Canada, *Prog. Rept. Pac.*, **81** : 75-79.

Tully, John P., 1950, Seasonal Cycles in the Sea. Fish. Res. Bd. Canada, *Prog. Rept. Pac.*, **85** : 88-90.

Hollister, H.J., 1951, Daily Sea Water Observations Along the West Coast of Vancouver Island. Fish. Res. Bd. Canada, *Prog. Rept. Pac.*, **86** : 6-11.

————, 1952, Daily Sea Water Observations in Northern British Columbia Waters. Fish. Res. Bd. Canada, *Prog. Rept. Pac.*, **91** : 3-9.

Tully, John P., 1952, Climate in the Coastal Seas of British Columbia. Fish. Res. Bd. Canada, *Prog. Rept. Pac.*, **90** : 16-20.

Hollister, H.J., 1953, Daily Sea Water Observations along the Central British Columbia Coast. Fish. Res. Bd. Canada, *Prog. Rept. Pac.*, **94** : 8-15.

————, 1953, Daily Sea Water Observations on the Pacific Coast of Canada. Fish. Res. Bd. Canada, Joint Comm. on Oceanogr., *MS Report*, 8 pp.

Pickard, G.L. and McLeod, D.C., 1953, The Seasonal Variations of the Temperature and Salinity of the Surface Waters of the British Columbia Coast, *J. Fish. Res. Bd. Canada*, **10** (3) : 125-145.

Hollister, H.J., 1954, What Was the Temperature of the Sea Water on the British Columbia Coast in 1952? Fish. Res. Bd. Canada, *Prog. Rept. Pac.*, **98** : 6-9.

————, 1956, The Program of Bathythermograph Observations at the Canadian Ocean Weather Station PAPA (50° 00′ N., 145° 00′ W.). Fish. Res. Bd. Canada, Joint Comm. on Oceanogr., *MS Report*, 17 pp.

Tabata, S., 1957, Classification of Daily Sea-Water Data, *Trans. Amer. Geophys. Union*, **38** (1) : 191-197.

TIDAL CURRENT STUDIES

Doe, L.A.E., 1950, Tidal Currents in Loudoun Channel. Fish. Res. Bd. Canada, *Prog. Rept. Pac.*, **84** (7) : 0-71.

Herlinveaux, R.H., 1953, How to Predict Tidal Currents in Juan de Fuca Strait. Fish. Res. Bd. Canada, *Prog. Rept. Pac.*, **95** : 48-51.

————, 1954, Surface Tidal Currents in Juan de Fuca Strait, *J. Fish. Res. Bd. Canada*, **11** (1) : 14-31.

————, 1954, Tidal Currents in Juan de Fuca Strait, *J. Fish. Res. Bd. Canada.* **11** (6) : 799-815.

LaCroix, G. Wilfred and Tully, John P., 1954, The Anomaly of Mean Sea Level in Seymour Narrows, British Columbia, *J. Fish. Res. Bd. Canada*, **11** (6) : 853-883.

Mackay, Bruce S., 1954, Tidal Current Observations in Hecate Strait, *J. Fish, Res. Bd. Canada*, **11** (1) : 48-56.

Barber, F.G. and Groll, A.W., 1955, Current Observations in Hecate Strait. Fish. Res. Bd. Canada, *Prog. Rept. Pac.*, **103** : 23-25.

Waldichuk, M. and Tabata, S., 1955, Oceanography of the Strait of Georgia, V. Surface Currents. Fish. Res. Bd. Canada, *Prog. Rept. Pac.*, **104** :30-33.

Barber, F.G., 1956, Current Observations North of Triangle Island, B.C. Fish. Res. Bd. Canada, *Prog. Rept. Pac.* (submitted for publication).

Herlinveaux, R.H., 1956, On Tidal Currents and Properties of the Sea Water Along the British Columbia Coast. Fish. Res. Bd. Canada, *Prog. Rept. Pac.* (submitted for publication).

Pickard, G.L., 1956, Surface and Bottom Currents in the Strait of Georgia, *J. Fish. Res. Bd. Canada*, **13** (4): 581-590.

Hydraulic Model Studies

Anonymous, 1950, Hydraulic Model of Alberni Harbour, Interim Report. Joint Comm. on Oceanorg., *MS Report*, 10 pp.

Pollard, R.A., 1953, Mechanical Alterations to the Alberni Harbour Model. Fish. Res. Bd. Canada, Joint Comm. on Oceanogr., *MS Report*, 22 pp.

Pollution Studies

Tully, John P., 1948, Pollution Research in Alberni Inlet. Fish. Res. Bd. Canada, *Prog. Rept. Pac.*, **76**: 66-71.

———, 1949, Prediction of Pulp Mill Pollution, *Paper Trade Journal*, pp. 1-6.

Fjarlie, R.L.I., 1950, The Oceanographic Phase of the Vancouver Sewage Problem. Fish. Res. Bd. Canada, Joint Comm. on Oceanogr., *MS Report*, 21 pp.

Tully, John P. and Waldichuk, M., 1953, Oceanographic Phase of the Nanaimo Sewage Problem. Fish. Res. Bd. Canada, Joint Comm. on Oceanogr., *MS Report*, 35 pp.

Waldichuk, M. and Tully, John P., 1953, Pollution Study in Nanaimo Harbour. Fish. Res. Bd. Canada, *Prog. Rept. Pac.*, **97**: 14-17.

Oceanographic Methods and Equipment

Carter, Neal M. and Tully, John P., 1937, A Graphical Method for the Conversion of Chlorinity per Litre to Chlorinity per Kilogram ($Cl\,°/_{oo}$) in Sea Water Analysis, *Journ. du Conseil*, **12** (1): 36-39.

Tully, John P., 1937, A Graphical Method for Calculating the Corrections on Deep Sea Reversing Thermometers, *Journ. du Conseil*, **12** (1): 40-44.

———, 1937, A Procedure for Increasing the Accuracy of Surface Current Charts, Based on Hydrodynamic Observations, *J. Biol. Bd. Canada*, **3** (2): 93-99.

Tully, John P., 1938, The Expression of Sea Water Analysis as Milligram Atoms per Litre, *Journ. du Conseil*, **13** (1): 67-70.

——— and Carter, Neal M., 1938, A Simplified Procedure for Colorimeter Analysis of Sea Water, *Journ. du Conseil*, **13** (1): 58-66.

Hollister, H.J., 1949, Notes on Taking Water Temperatures. Fish. Res. Bd. Canada, *Prog. Rept. Pac.*, **78**: 14-16.

Pickard, G.L., 1949, Simple Salinometers. Fish. Res. Bd. Canada, Joint Comm. on Oceanogr., *MS Report*, 8 pp.

———, 1951, Tables for Conversion of Chlorosity to Salinity. Institute of Oceanogr., University of British Columbia, *MS Report*, 11 pp.

Fjarlie, R.L.I., 1953, A Seawater Sampling Bottle. *Journ. Mar. Res.*, **12** (1): 21-30.

Harper, E.L., 1953, Semimicrodetermination of Dissolved Oxygen. *Anal. Chem.*, **25**: 1-4.

McCracken, L.H., 1955, The Salinity of Sea Water. Fish. Res. Bd. Canada, *Prog. Rept. Pac.*, **102**: 24-26.

———, 1956, A Simple Technique for Sealing Seawater Samples. Fish. Res. Bd. Canada, Joint Comm. on Oceanogr., *MS Report*, 3 pp.

Tabata, S. and Groll, A.W., 1956, Effect of Ship's Roll on the Ekman Current Meter, *Trans. Amer. Geophys. Union*, **34** (4): 425-428.

Strickland, J.D.H., 1957, Solar Radiation Penetrating the Ocean. Fish. Res. Bd. Canada, Joint Comm. on Oceanogr., *MS Report*, 43 pp.

——— ———, 1957, Standard Methods of Seawater Analyses. Fish. Res. Bd. Canada, Joint Comm. on Oceanogr., *MS Report*, **1**.

Standard Method No. Sal. 1. A. Determination of Salinity by Silver Nitrate Titration (high precision method), 9 pp.

Standard Method No. Sal. 2.A. Determination of Salinity by Silver Nitrate Titration (standard precision method), 8 pp.

Standard Method No. Sal. 3. A. Determination of Salinity by Conductivity Measurement, 19 pp.

Standard Method No. O. 1. A. Determination of Oxygen in Sea Water, 9 pp.

Standard Method No. P. 1. A. Determination of Inorganic Phosphorus (phosphate) in Sea Water, 10 pp.

Standard Method No. P. 2. A. Determination of Total Phosphorus in Sea Water (and organic phosphorus by difference), 14 pp.

Standard Method No. Si. 1. A. Determination of Soluble Silicate in Sea Water, 9 pp.

Standard Method No. N. 1. A. Determination of Nitrite in Sea Water, 7 pp.

Standard Method No. C. 1. A. Determination of Carbonate, Bicarbonate and Free Carbon Dioxide in Sea Water from pH and Alkalinity Measurements, 13 pp.

DATA RECORDS—OCEANIC SURVEYS

Pacific Oceanographic Group of the Fisheries Research Board of Canada

———, 1950, Pacific Coast Data Record, Offshore Survey, 1936. Joint Comm. on Oceanogr., *MS Report*, 39 pp.

———, 1952, Pacific Coast Data Record, Offshore Survey, August 1-14, 1951. Joint Comm. on Oceanogr., *MS Report*, 30 pp.

———, 1956, Physical, Chemical and Plankton Data Record, Project Norpac, July 26 to September 1, 1955. Joint Comm. on Oceanogr., *MS Report*, 202 pp.

———, 1956, Physical and Chemical Data Record, Approaches to Juan de Fuca Strait, 1936 - 1938. Joint Comm., on Oceanogr., *MS Report*, 99 pp.

———, 1957, Physical, Chemical and Plankton Data Record, North Pacific Survey, July 31 to September 2, 1956, with Appendix I, Marine Salmon Exploratory Fishing Surveys, May 22 to September 12, 1956. Joint Comm. on Oceanogr., *MS Report*, 191 pp.

———, 1957, Physical, Chemical and Plankton Data Record, North Pacific Survey, January 23 to March 4, 1957. Joint Comm. on Oceanogr., *MS Report*, 109 pp.

DATA RECORDS—SURVEYS IN COASTAL SEAWAYS

Pacific Oceanographic Group of the Fisheries Research Board of Canada

———, 1951, Data Record, Fraser River Estuary Project, 1950. Joint Comm. on Oceanogr., *MS Report*, 489 pp.

———, 1953, Physical and Chemical Data Record, Strait of Georgia, 1930, 1931, and 1932. Joint Comm. on Oceanogr., *MS Report*, 78 pp.

———, 1954, Physical and Chemical Data Record, Strait of Georgia, 1949 - 1953, with Appendix I, Current Measurements, March, 1953. Joint Comm. on Oceanogr., *MS Report*, 437 pp.

———, 1955, Data Record, Current Measurements, Hecate Project, 1954. Joint Comm. on Oceanogr., *MS Report*, 74 pp.

———, 1955, Physical and Chemical Data Record, Hecate Project, 1954. Joint Comm. on Oceanogr., *MS Report*, 99 pp.

———, 1955, Physical and Chemical Data Record, Juan de Fuca Strait Project 1951-1952 with Appendix I, Current Measurements. Joint Comm. on Oceanogr., *MS Report*, 182 pp.

———, 1955, Data Record, Barkley Sound, April 4-27, 1950. Joint Comm. on Oceanogr., *MS Report*, 39 pp.

———, 1956, Physical and Chemical Data Record, Dixon Entrance, Hecate Strait, Queen Charlotte Sound, 1934, 1937, 1938, 1951. Joint Comm. on Oceanogr., *MS Report*, 56 pp.

———, 1957, Physical and Chemical Data Record, Alberni Inlet and Harbour, 1939 and 1941. Joint Comm. on Oceanogr., *MS Report*, 89 pp.

Institute of Oceanography, University of British Columbia

———, 1953, Data Report No. 1, British Columbia Inlet Study, 1951, *MS Report*, 79 pp.

———, 1953, Data Report No. 2, British Columiba Inlet Cruises, 1952, *MS Report*, 14 pp.

DATA RECORDS—TIME SERIES OBSERVATIONS

Pacific Oceanographic Group of the Fisheries Research Board of Canada

————, 1957, Data Record, 1956, Ocean Weather Station PAPA (latitude 50°00′N., longitude 145°00′W.). Joint Comm. on Oceanogr., *MS Report*, 122 pp.

————, 1947-1957, Observation of Seawater Temperature and Salinity on the Pacific Coast of Canada. Joint Comm. on Oceanogr., *MS Reports:*

1947,	*1914 to 1934*,	**1:** 113 pp.
1947,	*1935 to 1937*,	**2:** 109 pp.
1948,	*1938 to 1939*,	**3:** 93 pp.
1948,	*1940 to 1941*,	**4:** 131 pp.
1948,	*1942 to 1943*,	**5:** 116 pp.
1948,	*1944 to 1945*,	**6:** 105 pp.
1949,	*1946 to 1947*,	**7:** 105 pp.
1949,	*1948*,	**8:** 55 pp.
1950,	*1949*,	**9:** 55 pp.
1951,	*1950*,	**10:** 59 pp.
1952,	*1951*,	**11:** 62 pp.
1953,	*1952*,	**12:** 58 pp.
1954,	*1953*,	**13:** 64 pp.
1955,	*1954*,	**14:** 86 pp.
1956,	*1955*,	**15:** 93 pp.
1957,	*1956*,	**16:** 90 pp. (App.)

GENERAL

Tully, John P., 1938, Oceanography. Fish. Res. Bd. Canada, *Prog. Rept. Pac.*, **35**: 1-4.

————, 1953, Oceanography-Science of the Sea, *Can. Geographical Journal*, pp. 2-19.

Walker, E.R., 1954, Marine Weather Services on the British Columbia Coast. Fish. Res. Bd. Canada, Joint Comm. on Oceanogr., *MS Report*, 6 pp.

Wickett, W.P. and Pollard, R.A., 1954, Measuring the Oxygen Supply to Salmon Redds. Fish. Res. Bd. Canada, *Prog. Rept. Pac.*, **99**: 20-21.

Tully, John P., 1954, Conditions for Troll Fishing. Fish. Res. Bd. Canada, *Prog. Rept. Pac.*, **101**: 12-16.

Pollard, R.A., 1955, Measuring Seepage through Salmon Spawning Gravels, *J. Fish. Res. Bd. Canada*, **12** (5): 706-741.

Terhune, L.D.B., 1957, Groundwater Standpipe Mark VI. Fish. Res. Bd. Canada, Joint Comm. on Oceanogr., *MS. Report*, 14 pp.

REPORT OF THE INSTITUTE OF OCEANOGRAPHY, UNIVERSITY OF BRITISH COLUMBIA

ROBERT F. SCAGEL

University of British Columbia, Vancouver, Canada.

INTRODUCTION

The prime function of the Insitute is to provide instruction at the graduate level in the field of oceanography. The instruction includes both the presentation of lecture courses in biological, chemical, geological and physical oceanography, and also the organization of research programmes for the students to give them training in field and laboratory procedures and in reporting their work. Each student takes introductory courses in all the main fields, advanced courses in his own scientific field, and carries out and prepares a thesis on a research project.

During the period 1954-56, two students have received their Ph.D. degrees (physical oceanography), and eight their M.A. (one in physical, two in chemical, one in botanical, and four in zoological oceanography). At present there are three working toward their Ph.D. degree and six students working toward their M.A.

RESEARCH

The research programme is centred on the inlets and coastal waters of British Columbia.

The basic study of the water characteristics in the inlets has been continued, chiefly through summer cruises by Dr. G. L. Pickard to the southern mainland inlets in 1954, 1955, and 1956; by Dr. R. F. Scagel to Saanich Inlet in 1954 and 1955; and by a monthly cruise program in Indian Arm started by Dr. Scagel in 1956. In addition, Dr. Scagel has been studying the water properties in a more extensive body, Queen Charlotte Strait, with special reference to the possible correlation between the distribution of benthonic organisms and the water properties and circulation. Studies of primary production are also underway.

Dr. Pickard has also been accumulating data on currents in some of the deep inlets by direct measurement. The main object here has been to try to get sufficient data to be able to separate the estuarial and tidal components. In addition, local current studies have been made at surface and bottom across Georgia Strait, and at the surface in Friday Harbor.

A number of observations of internal waves have been made in the inlets, some having tidal periods and others having periods of a few minutes. A study of particle distribution in inlet and coastal waters by a light scattering technique has recently been started. The object here is to investigate the particle distribution with a view to using it as a water mass tracer, and also to investigate the processes of deposition of the silt brought into the inlets by the rivers.

Dr. W.M. Cameron has been concerned for some years with a study of oceanographic conditions in the Beauforts Sea and adjacent waters and in 1955 completed a comprehensive report on the results of these investigations, including the dynamics of the circulations there.

Dr. R. W. Stewart, who joined the Institute in 1955, is particularly interested in fluid turbulence. He has beeen applying some of the current ideas on fluid turbulence to the oceans, with particular emphasis on the Reynold's stress terms and avoiding the rather crude "coefficient of eddy viscosity" concept.

Dr. W.H. Mathews has completed a study of bottom topography and sediments, and water circulation in Garibaldi Lake, B.C., a glacier fed lake at 5,000 feet elevation. He has also made a study of gravel deposition in Dixon Entrance, with the object of determining the sources of these materials.

Dr. Kirsch has been studying ionic ratios in certain sea waters diluted by river inflows.

During the last few years during the preparation of graduate work, particular attention has been given to studies of the Chaetognaths and Copepods by students in Biological Oceanography; these are published elsewhere.

A list of publications and reports follows:

Publications and Reports

Pickard, G.L. and Cameron, W.M., 1951, The Institute of Oceanography, University of British Columbia, *Trans. Amer. Geophys. Union*, **32** : 112-113.

Cameron, W.M., 1951, On the Transverse Forces in a British Columbia Inlet, *Trans. Roy. Soc. Canada*, Ser. III, **45** : 1-8.

Pickard, G.L. and McLeod, D.C., 1953, Seasonal Variation of Temperature and Salinity of Surface Water of the British Columbia Coast, *J. Fish. Res. Bd. Canada*, **10** : 125-145.

Pickard, G.L., 1953, Internal Waves in British Columbia Inlets, *Trans. Roy. Soc. Canada*, **47** : 136 (Abstract).

———, 1953, Characteristics of Waters of British Columbia Inlets, *Trans. Roy. Soc. Canada*, **47** : 171. (Abstract).

———, 1953, Oceanography of British Columbia Mainland Inlets: I. Water Characteristics, *Prog. Rep. Pac. Coast Stns.*, F.R.B. Can., **96** : 3-6.

———, 1953, Oceanography of British Columbia Mainland Inlets: II. Currents, *Prog. Rep. Pac. Coast Stns.*, F.R.B. Can., **97** : 12-13.

———, 1954, Oceanography of British Columbia Mainland Inlets : III. Internal Waves, *Prog. Rep. Coast Stns.*, F.R.B. Can., **98** : 13-16.

———, 1954, Oceanography of British Columbia Mainland Inlets: IV. Dissolved Oxygen Distribution, *Prog. Rep. Pac. Coast Stns.*, F.R. B. Can., **99** : 9-11.

———, 1955, British Columbia Inlets, *Trans. Amer. Geophys. Union*, **36** : 897-901.

Kirsch, M., 1956, Ionic Rations of Some of the Major Components in River-diluted Sea Water in Bute and Knight Inlets, British Columbia, *J. Fish. Res. Bd. Canada*, **13**: 273-289.

Trites, R.W., 1956, The Oceanography of Chatham Sound, British Columbia, *J. Fish. Res. Bd. Canada*, **13** : 385-434.

Pickard, G.L., 1956, Surface and Bottom Currents in the Strait of Georgia, *J. Fish. Res. Bd. Canada*, **13** : 58-1590.

———, Physical Features of British Columbia Inlets, *Trans. Roy. Soc. Canada*. (in press)

Tabata, S. and Pickard, G.L., The Physical Oceanography of Bute Inlet, *J. Fish. Res. Bd. Canada*. (in press)

Pickard, G.L. and Trites, R.W., Fresh Water Transport Determination from the Heat Budget with Applications to British Columbia Inlets, *J. Fish. Res. Bd. Canada*. (in press)

Clemens, W.A., Some Problems in Biological Oceanography on the British Columbia Coast, *Proc. Eighth Pac. Sci. Congress*. (in press)

Scagel, R.F., An Annotated List of the Marine Algae of British Columbia and Northern Washington, *Bull. Nat. Mus. Can.*, Ottawa: Queen's Printer. (in press)

———, 1956, Introduction of a Japanese Alga, *Sargassum muticum*, into the Northeast Pacific, *Fish. Res. Pap.*, Wash. State Dept. Fish., **1**(4) : 1-10, 14 figs.

———, 1956, Biological Oceanography in British Columbia, *Bull. Internat. Oceanog. Foundation*, **2**(3) : 166-172, 8 pls.

———, 1956, The Typification of the Genera of Rhodomelaceae, in Index Nominum Genicorum (Algae). Utrecht.

———, 1947, An Investigation of Marine Plants near Hardy Bay, *B.C. Prov. Fish. Dept.*, No. 1, 70 pp., 26 figs., 11 tables.

———, 1952, A Morphological Study of Some Dorsiventral Rhodomelaceae, *Univ. Calif. Publ., Bot.*, **27** (1) : 1-108, 20 figs.

DATA REPORTS

British Columbia Inlet Study, 1951 — March, 1953.

British Columbia Inlet Cruises, 1952 — April, 1953.

British Columbia Inlet Cruises, 1953 — April, 1954.

C.G.M.V. *Cancolim II* Survey of British Columbia Coast, 1953 — December, 1955.

Saanich Inlet Cruises, 1954, 1955 — December, 1955.

British Columbia Inlet Cruise, 1954 — December, 1955.

British Columbia Inlet Cruise, 1955 — December, 1955.

British Columbia Inlet Cruise, 1956 — October, 1956.

Queen Charlotte Strait, 1956 — November, 1956.

Indian Arm Cruises, 1956 — December, 1956.

REPORT ON PHYSICAL OCEANOGRAPHY—PACIFIC NAVAL LABORATORY—1954-57

PACIFIC NAVAL LABORATORY

Esquimalt, B.C., Canada.

A considerable proportion of the research conducted at Pacific Naval Laboratory involves experiments in the sea and accordingly requires a knowledge of physical oceanographic conditions. As this requirement is met in general by services provided by the Pacific Oceanographic Group, PNL does not have a programme of oceanographic research in the usual sense. However, certain activities are closely related to physical oceanography.

Research is being conducted into the phenomenon of turbulence as it occurs in the sea. To date the bulk of the effort has gone into the development of suitable instrumentation. The technique employed is an adaptation of hot wire anemometry as used in aerodynamics. A survey has been made of the effect of a large turbulence generator (a reef in a tidal stream), and a spectrum of turbulence scales several miles downstream determined. An increasing amount of small scale turbulence is found as the edge of the "wake" is approached. As suitable instrumentation techniques are developed, it is intended to observe natural turbulence phenomena in the deep water of the open sea. This programme will involve coordinated physical oceanographic observations.

There has been considerable interest at PNL in thermal microstructure in the sea because of its significance in propagation of sound. Instrumentation involving the use of thermistors to measure temperature to .001°C. and a time constant of .5 secs. has been developed. Considerable work has been conducted with this equipment but, for resolution of temperature structures down to the wave length of sound in question (about 10 cms.), has proven extremely difficult because of the very low water velocities which must be measured with a temperature element of this time constant. The present emphasis is on the production of temperature elements with a time constant of an order of magnitude less so that higher towing speeds can be used. This type of equipment has revealed details of thermal structure which completely escape the bathythermograph.

PNL Reports Relating to Physical Oceanography

Davis, P.A. and Patterson, A.M., 1956, The Creation and Propagation of Internal Waves: A Literature Survey, *PNL Technical Memorandum* **56** (2): 15 pp., 5 figs., 103 refs.

Patterson, A.M., Some Hot Wire Measurements of a Turbulence Spectrum in the Ocean. (*in preparation*).

REPORT OF THE HAWAII MARINE LABORATORY

A. H. BANNER

University of Hawaii, Honolulu, Hawaii.

Very little of the work which has been done at the Hawaii Marine Laboratory during the last five years could be classified as oceanography, but the following projects may be relevant.

1. Seasonal Variation in the Physical Environment of the Ponds of the Hawaii Marine Laboratory and the Adjacent Waters of Kaneohe Bay, July, 1953, *Pacific Science* by W.S.L. Tseu. This study was of tides, changes in temperature, salinity, and oxygen content of the waters immediately about the laboratory for a period of two years.

2. The use of C^{14} to determine the productivity of the open ocean; Dr. Doty has summarized the work as follows: "Working out of the Hawaii Marine Laboratory, Maxwell S. Doty, Chairman of the Department of Botany of the University, completed a fourteen month study of the phytoplankton productivity of the waters near the upwind shores of Oahu." This is published in *Journal du Conseil.* Other work done by this same group has involved similar studies utilizing carbon fourteen tracer techniques in determining phytoplankton productivity along the equatorial region from 110°W. to about 160°W. and in the region of 140 to 160°W. from the Society Islands in the south to about 40°N. latitude. The same primary productivity studies have been carried out in the Northern Marshalls and between Hawaii and the Northern Marshalls. A considerable amount of technique development has been done at Eniwetok Atoll utilizing the facilities of the Eniwetok Marine Biological Laboratory. Shore and reef productivity studies have been initiated or completed. They have been designed to reveal something of the contribution of the ocean and the land masses to the populations near shore. Pacific Oceanic Fishery Investigations vessels have been utilized for the high seas work.

3. Investigation of the deep scattering layer and illumination by Brian P. Boden and Elizabeth Kampa (of Scripps Institution of Oceanography, La Jolla, California). The facilities of the Hawaii Marine Laboratory were used by these investigators and the work is reported in *Pacific Science*, **11**, April, 1957.

4. The relation of salps to water masses in the tropical Pacific. The work, done in cooperation with the U.S. Fish and Wildlife Service, Pacific Oceanic Fishery Investigations, was carried on by James Yount. To date, he has published only the results of his systematic studies upon the salps.

Currently we have a study progressing on the seasonal variation in the zooplankton of Kaneohe Bay. Plans are now underway for a coordinated study of the waters of Kaneohe Bay with investigations of current system, the chemistry, meteorology, freshwater run-off from adjacent land, the bacteriology, and plant and animal plankton. If all goes well, some phases of this study will be initiated during the summer of 1957.

REVIEW OF POFI'S OCEANOGRAPHIC PROGRAM, JANUARY 1952 - JUNE 1957

MARY LYNNE GODFREY

Physical Science Aid, Pacific Oceanic Fishery Investigations, Honolulu, Hawaii.

In the research program of the Pacific Oceanic Fishery Investigations (POFI) of the U.S. Fish and Wildlife Service, the applications of physical oceanography are specialized in that the ocean is considered primarily as the physical and chemical environment of the tunas, particularly of the yellowfin, the skipjack, and the albacore. In such a consideration, the movements of the water in the euphotic zone, both horizontal and vertical, are of basic concern. As possible factors influencing the distribution and abundance of tunas, primarily in the central and eastern Pacific, POFI is concerned with wind-driven horizontal flows of the North Equatorial and South Equatorial Currents and the upwelling at or near the Equator, with eddies such as those near the Hawaiian Islands, and with zones of mixing such as the Polar Front in the North Pacific. The principal areas of interest to these oceanographic and fishery programs with associated tuna species, are shown in Fig. 1. They may be identified as the Hawaiian Offshore waters (skipjack), the Equatorial Pacific (principally yellowfin, also skipjack and albacore), and the North Pacific (albacore). Each specific area of investigation has required an individual approach, so each is treated separately in the following discussion.

POFI'S principal oceanographic research vessel, the *Hugh M. Smith*, and equipment were described by Cromwell *(3)* and Stroup *(12)*. Cromwell *(3, 4)* and King, *et. al. (6)* have explained in detail the methods of collecting and processing the data.

HAWAIIAN OFFSHORE WATERS

Since 1951, POFI has made five oceanographic cruises to survey the general circulation features of the Hawaiian offshore waters. The Hawaiian Islands lie across the westerly flowing North Equatorial Current and are normally under the influence of the northeast trades. Water movements near the islands are complex and variable.

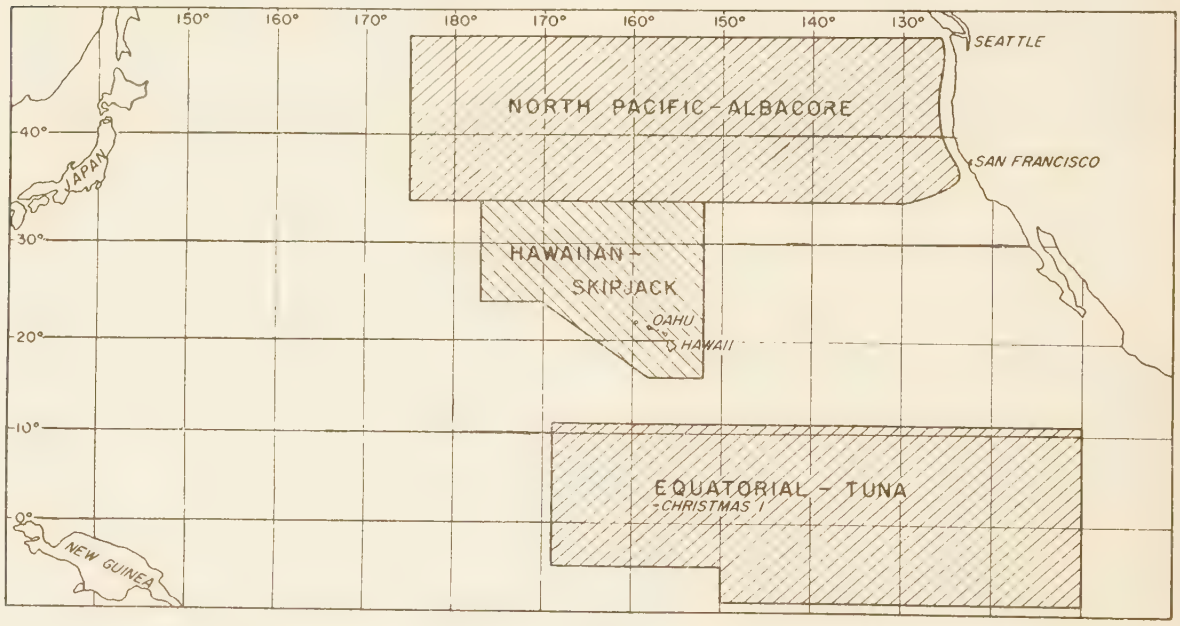


Fig. 1.—Principal areas of interest to POFI'S oceanographic and fishery surveys.

On the leeward side of the chain there is a system of semi-permanent eddies, regions where vertical water movement is suggested by the temperature structure. The seasonal variability and the general complexity of the area are discussed in detail by McGary *(7)* and Seckel *(10)*.

In April, 1953, the *Charles H. Gilbert* initiated a series of weekly observations of four oceanographic stations on a north-south section extending between the islands of Oahu and Molokai. This intensive study in a restricted area continued into December, and contributed to our understanding of the environmental factors influencing the island skipjack fishery. This "monitoring" type survey has recently been expanded by POFI with the cooperation of Territorial agencies. From November, 1955, weekly surface temperature and salinity samples have been collected at Koko Head on Oahu. At two-week intervals beginning early in 1956, *BT*'s and surface salinities have been taken off the leeward and windward shores of Oahu by the Division of Fish and Game vessel *Makua* and by the University of Hawaii's *Salpa*. A 45-station grid around the island of Oahu has been occupied four times a year (seasonally) since November, 1955, and there have been three surveys to date to study the direction and the volume of flow through the islands. Surface temperatures and salinity samples are now being collected weekly at (1) Ocean Weather Station Victor (34°N., 164°E.), (2) Midway Island, (3) French Frigate Shoals, (4) Upolu Point, Hawaii, (5) Johnston Island, and (6) Wake Island, and forwarded to POFI at about 12-week intervals. Finally, an atlas is in preparation which will describe oceanographic conditions of the surface layer in an area 10°N. by 30°N. latitude and 150°W. by 170°W. longitude.

EQUATORIAL PACIFIC

In 1950 and 1951, there were three oceanographic cruises *(11)* to the equatorial Pacific where enrichment and an associated increase in biological productivity were at first suspected and later revealed by these surveys. The oceanographic cruise of the *Hugh M. Smith* in early 1952 was in support of longline fishing in the equatorial Pacific *(1)*. The *Smith* examined a north-south section of this region across a band 300-400 miles wide centered on the Equator, to provide further information on the physical machanisms leading to biological enrichment.

Following these expeditions of a general exploratory nature, cruises were planned to study specific features. In the summer of 1952, *Smith* Cruise 15 investigated temporal variations in equatorial circulation. Four sections along 140° W. between 9°N. and 7°S. were completed in 23 days *(2)*. Later that same summer, another cruise of the *Smith* affirmed the existence beneath the Equator of an eastward flowing undercurrent, previously suggested by the drift of longline fishing gear *(5)*.

Specific needs have continued to shape more recent cruise plans. *Smith* Cruise 31, participating in the EASTROPIC expedition, September to December, 1955, investigated east-west gradients in oceanographic features and productivity along the northern boundary of the Countercurrent and along the Equator. EASTROPIC was a quasi-synoptic survey of the area between Christmas Island and the West Coast and also involved the Scripps Institution of Oceanography, the Inter-American Tropical Tuna Commisssion, the California Department of Fish and Game, and the Peruvian Hydrographic Office. *Smith* Cruise 33 during March, 1956 was planned to follow a parcel of newly upwelled water and to study the subsequent trophic successions. EQUAPAC was a more recent cooperative survey in which vessels from POFI and Scripps cooperated with those of Japan and France in a study of the equatorial Pacific between 132°W. longitude and the Philippines.

Prompted by the need for continuous observations, a station for recording ocean water temperatures and weather conditions was established on Christmas Island in October, 1953. The meteorological instruments were installed by POFI staff members and have been maintained by local island residents. In addition to the station, every opportunity has been taken to collect surface temperatures and salinities along transects across the Equator. Arrangements were made recently with the Matson Navigation Company to utilize the voyages of the S.S. *Mariposa* and the S.S. *Monterey*, running between Honolulu and Papeete and Honolulu and Pago, for such collections. By June, 1957, this cooperation had resulted in observations from nine equatorial crossings.

NORTH PACIFIC

The *Smith* Cruise in the winter of 1953-54 was the first of a series of surveys planned to describe the oceanography of the central, temperate North Pacific in connection with an investigation of the albacore tuna *(9)*. The scanty information available pointed to the existence of a transition zone

(Polar Front) between the easterly flowing subarctic waters of the Aleutian Current and the subtropical waters of the North Pacific Current. Seasonal variations in the position and intensity of this feature and the vastness of the area involved contributed to the complexity of the problem. The *Smith* explored the physical and chemical characteristics of the transition zone, first to the north and east of Hawaii and, in early 1955, to the north and west as far as 172°E. In the fall of 1954, the *Gilbert* made similar investigations to the north and west of Hawaii followed by a winter trip working north of Hawaii to 40°N. Both vessels operated in conjunction with experimental fishing cruises. The albacore study was given impetus in October, 1954 by an allotment of funds through the Saltonstall-Kennedy Act.

Because of the need for a quasi-synoptic study of oceanic conditions across the broad stretch of the North Pacific, Norpac *(8)* was conceived and, in the summer of 1955, was executed by vessels of Canada, Japan, and the United States. This joint survey was the first of its kind in the Pacific north of 20°N. latitude, and provided a wealth of information which will serve "as background for fisheries investigations and for effectively describing the circulation" *(9)*. This multiple-vessel type of operation will again be employed during the coming IGY to examine the relation between albacore distribution and the transition zone, or Polar Front.

GENERAL

In addition to the formal oceanographic surveys described above, routine observations on numerous fishing cruises have included *BT* loweringS, continuous records of surface temperature, water color and transparency measurements, surface phosphate and salinity determinations, and standard marine weather observations.

LITERATURE CITED

(1) Austin, Thomas S., 1954a, Mid-Pacific Oceanography: Part III, Transequatorial Waters, August-October 1951, *U.S. Fish and Wildlife Service, Spec. Sci. Rept.* (Fish.), **131**: 51 pp.

(2) ———, 1954b, Mid-Pacific Oceanography: Part V, Transequatorial Water, May-June 1952, August 1952, *U.S. Fish and Wildlife Service, Spec. Sci. Rept.* (Fish.), **136**: 86 pp.

(3) Cromwell, Townsend, 1951, Mid-Pacific Oceanography, January-March 1950. *U.S. Fish and Wildlife Service, Spec. Sci. Rept.* (Fish.), **54**: 76 pp.

(4) ———, 1954, Mid-Pacific Oceanography: Part II, Transequatorial Waters, June-August 1950, Junuary-March 1951, *U.S. Fish and Wildlife Service, Spec. Sci. Rept.* (Fish.), **131**: 180 pp.

(5) Montgomery, R.B. and Stroup, E.D., 1954, Equatorial Undercurrent in Pacific Ocean Revealed by New Methods, *Science*, **119** (3097): 648-649.

(6) King, Joseph E., Austin, T.S. and Doty, M.S., 1957, Preliminary Report on Expedition EASTROPIC, *U.S. Fish and Wildlife Service, Spec. Sci. Rept.* (Fish.), **201**: 155 pp.

(7) McGary, James W., 1955, Mid-Pacific Oceanography: Part VI, Hawaiian Offshore Water, December 1949-November 1951, *U.S. Fish and Wildlife Service, Spec. Sci. Rept.* (Fish.), **152**: 138 pp.

(8) McGary, James W., June, E.C. and Austin, T.S., 1956, Mid-Pacific Oceanography: Part IX, Operation NORPAC, *U.S. Fish and Wildlife Service, Spec. Sci. Rept.* (Fish.), **168**: 127 pp.

(9) McGary, James W. and Stroup, E.D., 1956, Mid-Pacific Oceanography: Part VIII, Middle Latitude Waters, January-March 1954, *U.S. Fish and Wildlife Service, Spec. Sci. Rept.* (Fish.), **180**; 173 pp.

(10) Seckel, Gunter R., 1955, Mid-Pacific Oceanography: Part VII, Hawaiian Offshore Waters, September 1952-August 1953, *U.S. Fish and Wildlife Service, Spec. Sci. Rept.* (Fish.), **164**: 250 pp.

(11) Sette, Oscar E. and Staff of POFI, 1954, Progress in Pacific Oceanic Fishery Investigations 1950-53, *U.S. Fish and Wildlife Service, Spec. Sci. Rept.* (Fish.), **116**: 75 pp.

(12) Stroup, Edward D., 1954, Mid-Pacific Oceanography: Part IV, Transequatorial Waters, January-March 1952, *U.S. Fish and Wildlife Service, Spec. Sci. Rept.* (Fish.), **135**: 52 pp.

PHYSICAL OCEANOGRAPHY IN INDONESIA, 1954-1957

KLAUS WYRTKI

Institute of Marine Research, Djakarta-Kota, Indonesia.

The Institute of Marine Research in Djakarta has made several surveys within the Indonesian Archipelago with its research vessel *Samudera*. These were carried out in order to get more information on the homogeneity of the waters over the Sunda Shelf and to complete the observations of the Snellius Expedition in regions where observations are available only in one season, (Oceanographic Station List, 1956).

The survey of the surface salinities in the whole southeast Asian region has been continued, and from January, 1955 monthly charts of the surface salinity have been drawn and distributed. Later on the charts of the former years were also published *(1)*. An introduction to these charts has been given by Wyrtki *(5)*.

Investigations on the annual variation and the distribution of surface salinity along the north coast of Java and in the Strait of Malacca were published by Soeriaatmadja *(2, 3)*. It could be stated that the distribution depends chiefly on the movements of watermasses due to the monsoons.

An investigation on the subtropical Lower Water, entering the Indonesian waters from the Pacific, by Wyrtki *(4)* shows that two different water types are engaged in this process, and that their movements within the discontinuity layer are in close relation to the surface currents.

The distribution of rainfall over the Indonesian waters has been investigated by Wyrtki *(6)* in order to get information on its possible influence on surface salinities. It could be shown that the rainfall is smaller than assumed by previous authors. Most of the regions have a rainfall below 200 cm/year.

In progress are investigations on the general circulation on the surface of the southeast Asian waters, and on the properties and the vertical extension of the surface layer, as well as on the energy exchange at the surface. The influence of the monsoons on the currents and the sea level has been studied, and close correlations could be found. The water transport through the Archipelago during the different seasons could be calculated, and it could be shown that only a very small water exchange which is closely correlated with upwelling processes takes place from the Pacific to the Indian Ocean.

REFERENCES

(1) Hardenberg, J.D.F. and Soeriaatmadja, Rd. E., 1956, Monthly Mean Salinities in the Indonesian Archipelago and Adjacent Waters from the Months of Feb. 1950 - 1955, *O.S.R. Bull.*, **21**.

(2) Soeriaatmadja, Rd. E., 1956, Seasonal Fluctuations in the Surface Salinity off the North Coast of Java, *Penjelidikan Laut di Indonesia* (Mar. Res. in Indonesia) No. 1.

(3) ————, 1957, Surface Salinities in the Strait of Malacca, *Penjelidikan Laut di Indonesia* (Mar. Res. in Indonesia) No. 2.

(4) Wyrtki, K., 1956, The Subtropical Lower Water between the Philippines and Irian (New Guinea), *Penjelidikan Laut di Indonesia* (Mar. Res. in Indonesia) No. 1.

(5) ————, 1956, Monthly Charts of Surface Salinity in Indonesian and Adjacent Waters, *Journ. du Conseil*, **21** (3).

(6) ————, 1956, The Rainfall over the Indonesian Waters, *Lembaga Meteorologi dan Geofysik, Verhandelingen*, **49**.

PHYSICAL OCEANOGRAPHY IN JAPAN IN THE PERIOD 1954 - 57

KOJI HIDAKA and KOZO YOSHIDA

Tokyo University, Tokyo, Japan.

This is the report on the activities in physical oceanography in Japan for the years 1954 - 57. A summary of the official and personal activities in the universities, institutions, and government organizations will be reviewed briefly in the following lines.

Oceanographic Observations During The Period 1954 - 57

Our regular cruises cover the large areas adjacent to our islands.

The oceanographic observations have been made with the vessels of various agencies such as JHO (Japanese Hydrographic Office), seven regional FRL's (Regional Fisheries Research Laboratory), JMA (Japanese Meteorological Agency), formerly called CMO (Central Meteorological Observatory), including its four subordinate marine observatories, and TFU (Tokyo University of Fisheries). The elements observed cover almost all aspects of oceanography.

Facilities and equipment for these ship observations have not been much improved, so that the hydrographic cast is in most cases limited to the levels shallower than 1,000 to 1,500 meters. Recently *BT* and *GEK* have begun to be used regularly with considerably frequent intervals while ships are under way. By the use of *BT* and *GEK* we can obtain more readily and rapidly than before the detailed structure of oceanic fields which had been left unexplored. Many of our ships are now equipped with loran and radar. Simultaneity of the observations should also be highly desired.

JHO (Japanese Hydrographic Office) has been carrying out more or less regular cruises with vessels such as *Kaiyo Maru No. 4*, *Meiyo Maru*, and *Shoyo Maru*, covering practically entire regions adjacent to Japan. In addition, some specially planned observations of currents and waves have occasionally been made.

TFRL (Tokai Regional Fisheries Research Laboratory) made an expedition in the Bering Sea with the vessel *Tenyo Maru* in the summers of 1954, 1955, and 1956, occupying about ninety stations each year. TFRL has made regular cruises over the areas off the Pacific coasts of Japan with *Tenyo Maru* and *Soyo Maru*. THFRL (Tohoku Regional Fisheries Research Laboratory) has been engaged in observations in Tohoku areas off the northeastern coasts of Honshu. JFRL (Japan Sea Regional Fisheries Research Laboratory) has worked on the survey in the Japan Sea. These and other regional FRL's work on oceanographic observations principally in connection with their fisheries researches.

The Oceanographical Section of JMA (Japanese Meteorological Agency) has carried out regular surveys in the large areas to the east of Honshu in each season with *Ryofu Maru*. In addition, *Asashio Maru* made routine cruises in bays such as Sagami Bay and Tokyo Bay.

Weather ship observations at the fixed station, Stn. X (39°N., 153°E.), were suspended at the end of 1953. At another ocean weather station, Stn. T (29°N., 135°E.), oceanographic observations have been made during the summer every year since 1954. HMO's (Hakodate Marine Observatory) regular cruises with *Yushio Maru* have been exploring the seas to the northeast of Japan, occasionally the waters off Hokkaido and the northern part of the Japan Sea. KMO (Kobe Marine Observatory), *Shumpu Maru* has surveyed the south of Honshu, including the Kuroshio region and has also made shallow sea observations in Osaka Bay, Kii - Suido and so on. MMO (Maizuru Marine Observatory) uses *Kuroshio Maru* to survey the Wakasa Bay, Maizuru Bay, and surrounding areas in Japan sea. NMO (Nagasaki Marine Observatory) with *Umikaze Maru* surveyed the adjacent seas of Kyushu.

The training ships *Umitaka Maru*, *Shinyo Maru*, and *Seicho Maru* of the TFU have been engaged in the oceanographic cruises for the survey of the Kuroshio region and geological research of the sea floors. In 1956-57, *Umitaka Maru* investigated the oceanographic conditions in the Indian Ocean and the Antarctic Ocean in the course of her cruise to the Antarctic accompanying the Maritime Safety Agency's *Soya*, which took part in the Antarctic Research Expedition in the International Geophysical Year.

In June, 1954 and 1956, the *Shunkotsu Maru* of the Fisheries Institute, Shimonoseki, surveyed the area around Bikini Atoll to measure the circulation and distribution of radioactivity in the region.

Participating in Norpac Expedition Project, as a cooperative work with the United States and Canada, our oceanographers carried out observations with fifteen vessels over the western North Pacific during the summer of 1955. They completed their scheduled observations, and the data obtained were tentatively issued by each agency or institution which took part in this project. The final results are to be summarized after joint meetings with American and Canadian oceanographers at Honolulu in February, 1956 and at Kyoto in March, 1957.

Participating in another international joint work with the United States and Peru, the Equapac Expedition, seven vessels of JHO, Fisheries Agencies, TFU, Kagoshima University, and Shizuoka Fisheries Laboratory executed oceanographic observations in the western Equatorial Pacific during the summer of 1956.

Participating in the IGY program, starting in 1957, we are planning extensive ship operations as well as island observations. Almost all of our research vessels will be used in this program.

Three-Agency Marine Research Coordination Council

Three government agencies, e.g., Hydrographic Office of Maritime Safety Agency, Fisheries Research Laboratories, and Meteorological Agencies meet in negotiations about three times every year in order to coordinate and cooperate in the work. The representatives of each agency show one another the results of their observations and expeditions after the preceding meeting, and confer about plans and areas to be explored by each agency in the subsequent period so that they may not be overlapped one upon the other.

Section of Physical Oceanography, National Committee for Geophysics

This is a committee established in the Science Council of Japan to keep liaison with the International Union of Geodesy and Geophysics. The Section of Physical Oceanography has about ten members of which Dr. Koji Hidaka is chairman and Dr. Michitaka Uda the secretary.

A sub-committee has been appointed in this section on the preparation of standard sea water with Dr. Yasuo Miyake as chairman. As the administration of the standard sea water must be international, it is agreed by home oceanographers that this sub-committee should be dismissed as soon as the international standards become available in this country. It was only 1952 when we could have Copenhagen water in Japan.

In accordance with the rapidly increasing necessity for international cooperation in oceanographic observations on a world-wide scale, a subcommittee was established specifically for cooperative oceanographic operations in 1956.

In this committee, we now have working groups for IGY, for Equapac, and for JOTI (Japanese Organization for Tsunami Investigation; see *Tsunami* under Long Waves).

The Oceanographical Society of Japan

This scientific society was established in January, 1941 with Dr. Takematsu Okada as the president. The president is now Dr. Koji Hidaka. Prior to 1951, the society had issued a popular monthly journal, *Journal of the Oceanographical Society of Japan.*

Pacific Science Investigations

Dr. Shinkishi Hatai, who had long worked as Japan's representative on the Pacific Science Council, resigned in 1950 and Dr. Koji Kidaka succeeded him. However, Dr. Hatai is still very active as the chairman of the Pacific Science Liaison Committee of the Science Council of Japan, which has about thirty members. Hidaka is also acting as the general manager of this committee which is in close cooperation with the Pacific Science Council Secretariat in Honolulu. At the present, Dr. Hidaka is the chairman of the Sub-committee on Physical Oceanography of the Standing Committee on Oceanography of the Pacific Science Association.

Cooperation with Unesco

The Japanese National Commission for Unesco appointed Dr. Koji Hidaka to propose a project in oceanography which would be useful in promoting the living standards of the Japanese people. This study was to be a basic one having close relation with the exploration of marine resources. The efforts have been concentrated on the exploration of the Kuroshio and the Inland Sea of Japan. The government contributed funds for this Unesco project.

In October, 1955, the regional meetings of the Representatives of Marine Sciences Institutes and the meetings of the International Advisory Committee on Marine Sciences were held in Tokyo under the auspices of Unesco. Dr. Hidaka was appointed a member of the International Advisory Committee on Marine Sciences. At the same time, the Regional Symposium on Physical Oceanography was held, and a number of papers on oceanographic instrumentation and oceanic circulation were presented.

International Geophysical Year

Japanese IGY cooperation began in June, 1955 when Dr. R.R. Revelle and Dr. Gordon Lill came to Japan and discussed this plan with us. The IGY program was prepared by the Section of Working Group, National Committee for the International Geophysical Year, with Dr. Koji Hidaka as Chairman. The final international discussion was held in Goteborg, Sweden in January, 1957, half a year in advance of the commencement of the operations. Dr. Hidaka and Dr. K. Suda, Chief Hydrographer, attended this conference. The operations to be carried out in the IGY Period are: (1) Multiple Ship Current Measurements in Polar Front Region, June - July, 1957; (2) Polar Front Survey in October, 1957; (3) Multiple Ship Current Measurements in the equatorial region in March and August, 1958; (4) Deep Water Circulation Survey in August, 1958.

The first fleet consisting of several ships left Tokyo on July 7, 1957, and were engaged in the operation on Multiple Ship Current Measurements in the Polar Front region to the east of our islands.

Waves

Little progress has been made during the period concerning the air-sea boundary processes or energy transfer from wind to waves. A model tank study on such processes has been attempted at the Disaster Prevention Research Institute, Kyoto University, under the direction of S. Hayami. Laboratory experiments on surf were carried out by Hayami in relation to beach erosion processes. From this, he established a relation between bottom slope and critical wave steepness which gives a transition from spilling breaker to plunging breaker. In addition, he and his colleague made field observations of waves, wave-currents, and shoreline changes at various beaches in cooperation with coastal engineers.

Measurements of waves have been made at various coastal stations such as those of the Meteorological Research Institute, the Japanese Hydrographic Office, and the Transportation Technical Research Institute. Wave measurements by means of stereo camera were made by shipbuilding engineers on board the *Nissei Maru* with special reference to their effects on the ship (*Report of the Shipbuilding Research Association of Japan*, Tokyo, 1954). It is evident that closer cooperation between the shipbuilding engineers and oceanographers is highly desirable and should be fruitful at the present time. A cooperative research program has recently been commenced, and measurements of waves with use of a radio-altimeter are now being planned. Various types of wave recorders have been devised, but few of them have been installed for routine continuous recording (see Instruments).

Forecasting of waves and swell has been extensively studied by S. Unoki and M. Nakano based on the wave records obtained continuously at the coast stations in Hachijo Island and Jogashima [*MGP*, **4** (3-4), 1953; *ROWJ* **2** (1), 1955; *MGP*, **6** (1), 1955; *AIOP*, **6**, 1955].[1] A practical technique has been devised for forecasting on a basis of empirical data, waves and swells caused by typhoons. Their work on wave characteristics such as height and period in relation to the passage of atmospheric low pressure, typhoons and fronts is also of special value. Unoki is now working on waves and swell within the area of typhoons by examining various available data on past typhoons. In addition, Unoki's summary result from his study on characteristics of sea and swell at various coasts of Japan is of practical importance. This study was based on a large number of visual observations [*MGP*, **6** (2), 1955].

A note on sea disasters of fishing boats caused by gusty storms and "shionami" (abnormally steep pyramidal wave in ugly seas) was published by M. Uda (*JNSJ*, **12**, 1955). He described the situations for two cases which occurred in 1952, and pointed out that the gusty storms in company with the passage of cold fronts were responsible. On July 28, 1955, a tragic accident happened at Nakagawa beach, Tu City, which killed 36 schoolgirls while swimming. Abnormal oceanographic conditions which might have been responsible for this tragedy were studied by T. Nan'niti. His tentative conclusion from current measurements seems to suggest that longshore currents

[1] All bibliographical abbreviations refer to the list at the end of this paper.

accompanying typhoon No. 13 might have been abnormally strong at this time [*JOSJ*, **11**(4), 1955].

T. Abe's study on the foaming of sea water came, in 1956, to the interesting stage of comparing his model with some field data of ocean waves [*JOSJ*, **12** (2), 1956; *MGP*, **6** (2), 1955].

Long Waves

In connection with the long-wave observations of the IGY program, two Van Dorn long-wave recorders are now in the process of being installed at Miyagi-Enoshima and at Hachijo Island.

Tsunami. No large tsunamis associated with submarine earthquakes have struck our coasts during the period. On the other hand, a research group JOTI (The Japanese Organization for Tsunami Investigations) was established in October, 1956, to make basic studies on tsunamis with the cooperation of the Scripps Institution of Oceanography. Dr. R. Takahasi is the chairman of JOTI. Various Problems such as generation, propagation, and coastal effects of tsunamis are being undertaken extensively by the member staffs.

H. Miyoshi has published a series of interesting papers on more or less theoretical problems of tsunamis [*JOSJ*, **10** (1) and (2), 1954; *ROWJ*, **2** (1), 1955; *JOSJ*, **11** (3), 1955]. He took account of the compressibility of water which might not be entirely negligible in a theory of generation of tsunamis. He examined mathematically compressional disturbances accompanying tsunamis. He also indicated theoretically that energy of tsunami waves will be only a small fraction of the total energy of the bottom deformation. Based on directional distributions of observed wave heights, he suggested that a number of recent tsunamis revealed their directivity which might be essential to a future warning.

H. Watanabe studied the tsunamis on tide-gauge records in the cases of earthquakes off Tokachi and of several other earthquakes [*KJ*, **5** (6), 1953; *KJ*, **7** (9), 1955; *GM*, **27**: (1), 1956].

Another interesting phase of tsunamis has been revealed by analyzing records of long waves caused by the eruption of a submarine volcano, the Myojin Reef, in September, 1952. S. Unoki and M. Nakano accounted for the recorded features of the long waves successfully as Cauchy-Poisson waves which were generated by this eruption [*JMR*, **13**(1),1954]. The waves were recorded at the Hachijo Island. The periods of waves were 95 seconds initially and diminished gradually to 30 seconds in one hour. Distinct beat phenomena were observed. On the other hand, H. Miyoshi and Y. Akiba ascribed the beats to a prism-like action of an island located on the way along which the tsunamis travelled [*JOSJ*, **10** (2), 1954]. In order to account for various facts revealed in the eruptions of Myojin Reef, Miyoshi examined possibilities of the behaviors of explosion waves accompanying the eruptions [*JOSJ*, **11** (4), 1955].

On several occasions in March to May of 1954, some of our tide gauges along the Pacific coast of Japan recorded striking oscillations of sea level. By examining the travel time of the waves, M. Nakano wrote that the origins were very likely to be the H-Bomb experiments at the Bikini Atoll in March to May of 1954 [Reports on Radiation Effect, *Japan Science Congress*, 1955; *JOSJ*, **11** (4), 1955].

Storm Surge. Very destructive storms urge did not occur during the period, and only a few papers appeared on this problem. M. Miyazaki has continued studies on this problem. In 1955, he worked on statistics of storm surges which occurred at Kobe harbor during the last 30 years [*OM*, **7** (1), 1955]. In 1956, he published an elaborate paper on a theory of storm surge [*GM*, **27** (3), 1956]. Model experiments on storm surge travelling up the rivers and canals in Osaka City were carried out by S. Hayami, K. Yawo, S. Adachi, and S. Kunishi. A solitary wave similar to storm tsunamis was generated by means of pneumatic wave generator (*DPRIB*, **9**, 1955). T. Ichiye wrote a paper on abnormally high waters due to storm in a river, in which a decay of wave with distance from the mouth of the river was discussed (*OM*, **5**, 1954).

Seiches. S. Ishiguro and A. Fujiki used an electronic analogue computer for analyzing the oscillations of water in a bay or a lake [*KK*, **6** (2-4), 1954; *JOSJ*, **11** (4), 1955; see Instruments].

The secondary oscillations or seiches in the Bay of Nagasaki were studied by K. Terada, Z. Yasui and Ishiguro extensively in connection with a harbor construction problem (*NMOR*, **4**, 1953; *KK*, ibid.). T. Ichiye wrote a note on a theory of the dissipation of seiche [*JOSJ*, **11** (3), 1955].

Tides and Tidal Currents

Using the method of studying the oscillation of water in a bay or lake by hydraulic model

experiments and by electronic ones (using an electronic analogue computer) developed by Ishiguro. I. Nakamura *et al.* worked on tides and tidal currents in the Ariake Sea [*KH*, **3** (4), 1954 Nagasaki Marine Observatory, 1954]. K. Iwata; devised a method for estimating tidal currents in a narrow channel from the information of tides along the coasts and harmonic constant for tidal current at a point in the channel, and applied this to the Kii Suido [*ROWJ*, **2** (1), 1955; *HB*, Spec. **17**, 1955]. He also pointed out discrepancies between observations and existing theories as to tides in a river, based on the observations of tides along the River of Tone (*HB*, **34**, 1954). Observations of tidal currents were carried out in various shallow seas by T. Ichiye and his colleague, and Ichiye discussed turbulence associated with the currents. He also worked on tides and tidal currents in the Aji River (*KH*, **2**, 1953; *KH*, **3**, 1953; *KH*, **4**, 1954; Report on Beach Erosion in the southern part of Osaka Bay, *Technical Report*, Osaka-wan Kowan-gijyutsu Chosakai, 1954). Ichiye further published a theory on the friction in tidal currents (*OM*, **7**, 1955). Ma Miyazaki devised a method for harmonic analysis of tides by use of the data for a month, with an application of the principles of the T.I. method for the short period analysis [*JOSJ*, **12** (1), 1956]. R. Saito and K. Igarashi discussed a method of tidal analysis with IBM machine.

Mean Sea Level

Ma Miyazaki discussed the seasonal variations in sea level along the Japanese coasts. From the tide records at twenty-five stations, where the period of observations exceeds fifteen years, harmonic constants for the annual and semiannual tides are computed. Effects of water density, atmospheric pressure, and some other local disturbances upon the variations are examined [*ROWJ*, **2** (3), 1955]. Based on statistics from the past records (*ERIB*, **33**, 1955), S. Yamaguchi found that an abrupt drop in monthly mean sea level occurred one month in advance of the month when great earthquakes took place.

Circulation

Theory of Oceanic Circulation. K. Hidaka published a series of papers on theoretical studies of general circulation of the oceans. The results from his elaborate work on circulation in the Pacific indicate that the wind-driven currents extend appreciably down to depths of several hundred meters (*Pacific Science* **9**, 1955). Deformation of ocean surface associated with wind-driven circulation was discussed; the obtained deformation appeared to be much greater than has ever been known unless lateral mixing is assumed to be much more intense than usually accepted [*JOSJ*, **10** (4), 1954].

Hidaka has further attempted to determine the distribution of vertical velocity associated with wind-induced circulation, and obtained a pattern of surface divergence over the Pacific which appears reasonable [*JJG*, **1** (2), 1955]. These theories are all based on an assumption of homogeneous oceans, neglecting effects of stratification. On the other hand, the employed wind stress distributions are based on statistical wind data which are quite realistic, and the general features which Hidaka obtained appear to be consistent with ever ones observed. During a year's stay at Texas A. & M. College, Hidaka wrote a paper on a theory of upwelling and coastal current under an assumed model, and obtained a result which may account for the processes off the California and Peruvian coasts. Lateral mixing plays an essential role in his assumed system to lead to a vertical circulation as observed [*TAGU*, **35** (3), 1954]. A new integral expression for wind-driven currents was obtained by Hidaka [*JJG*, **1** (2), 1955], with its application to the two-layer zonal ocean. He obtained the slopes of sea surface and thermocline as well as the vertical distribution of the currents. Recently Hidaka made a theoretical attempt to examine the effect of mixing on the geotrophic currents [*JOSJ*, **12** (4), 1956].

K. Takano published a paper on the Antarctic Circumpolar Current [*ROWJ*, **2** (1), 1955], assuming a specified density distribution, and pointed out that a reasonable result for the vertical distribution of velocity would be obtained if lateral eddy viscosity was assumed to be as large as 10^{10} c.g.s.

Hidaka [*JJG*, **1** (2), 1955] and M. Tsuchiya [*JOSJ*, **11** (1), 1955] obtained independently methods for dynamic computation of currents near and at the equator where the usual method is not valid. Tsuchiya worked out actual computations on his method, by use of recent data from the Hawaiian cruises, and found that the obtained results looked reasonable. In another paper, Tsuchiya [*ROWJ*, **2** (2), 1955] examined the validity of the assumptions on which his simplified method was based. The method might promise to give us more detailed information on circulation near the Equator when future observations cover the equatorial region more densely. In connection with equatorial dynamics, K. Yoshida [*JOSJ*, **11** (2), 1955]

pointed out that the dynamical balance discussed by Weenink and Groen (1953) appears to lead to a discontinuity in meridianal mass transport at the Equator as far as Reid's density model is assumed at the lowest latitudes. More realistic density structure such as revealed by recent observations in the region was found to yield a reasonable result, which might give validity to the third method for practical computation of equatorial currents originally given by Weenink and Groen.

K. Takano (*ROWJ*, **2**: 1, 1955) computed an example of thermal convective current in a rectangular canal, infinitely long in the east-west direction, 6,500 km. in width and 4,000 m. in depth. The latitudinal distribution of surface temperature difference was found to be of an order of 10 cm. per sec. Takano [*ROWJ*, **2** (2), 1955; *JOSJ*, **11** (2), 1955; *JOSJ*, **11** (3), 1955] has recently made a new approach to evaluate an oceanic circulation which could be generated and maintained by purely thermohaline processes. Surface density distribution was assigned as a simple function of latitude, the distribution of subsurface density was determined by diffusion of heat and salt in the water under the assumption of no advectional change in density, and the circulation was derived from the resulting density distribution. The results indicate that intense upwelling occurs very near the Equator and also near the western boundary of the ocean, whereas intense sinking appears near the eastern boundary. Strong poleward currents are encountered near the western and eastern boundaries.

Takano made a further attempt to estimate theoretically the relative importance of the thermal effect and the wind stress effect upon a large scale ocean circulation [*CR*, **242** (18), 1956]. The maintenance of ocean circulation was discussed by H. Arakawa from the standpoint of energy exchange between turbulence and the main current. The conversion of the eddy kinetic energy into the mean kinetic energy of the ocean circulation might be possible if the velocity shear was suitable, such as seen in an area of the inner part of the circulation (*JOSJ*, **9**, 1954).

Fluctuations in oceanic circulation. The fluctuation of circulation has been studied by M. Uda, J. Masuzawa, D. Shoji, T. Ichiye, M. Koizumi, S. Moriyasu, H. Kawai, K. Kajiura, K. Yoshida, T. Nan'niti and J. Fukuoka. Although more simultaneity and density of the observations are needed to find those time variations, more or less concentrated efforts have been made in deriving basic features of those changes from available observations.

Oceanographic observations at a fixed point (39° N., 153° E.) in the North Pacific have been continued, and data have now been accumulated for use. M. Koizumi published a series of papers during 1955 and 1956 on the variations of oceanographic conditions in the region of the ocean weather station "Extra" (39° N., 153° E.) and "Tango" (29° N., 135° E.), "normal monthly values" being computed for some of the oceanographic elements. Annual variations are also discussed, comparison being made between the two regions [*MGP*, **6** (2), 1955]. In the second paper, Koizumi discusses the annual variations in air temperature, sea-surface temperature, and wind [*MGP*, **6** (3-4), 1956]. In the third, the heat budget in the regions is discussed. This may explain the observed annual variations in hydrographic conditions. This conclusion indicates that the amount of heat brought into the region (Stn. "Extra") by ocean currents is quite comparable to the amount of heat used for evaporation [*MGP*, **7** (2), 1956]. Based on variations in mean sea level at several tide stations, those in Kuroshio were studied by D. Shoji (*HB*, Spec. **14**, 1954). He found a fluctuation with a period of about twenty days in the Kuroshio, and also found that abrupt changes in mean sea level were associated with abnormal conditions in the coastal currents (Dai - Kyucho in Japanese). A similar study was reported by Shoji, T. Kubota and S. Yoshida (Kaiyo Shigen Kaihatsu Chosa Hokoku, 1954). S. Hikosaka found that the variation in the currents in Tsugaru Strait, obtained from continuous records of a current meter, was in close correlation with that in the difference in mean sea level across the current. He found that the periods of the fluctuation were two weeks to a month. The origin of these fluctuations with periods of two weeks to a month as detected by the long-continued observations at the fixed point and also by the sea-level records is obscure, and deserves further study.

J. Masuzawa published papers on currents and water masses of the Kuroshio System [*OM*, **6** (1), 1954; *KH*, **3** (4), 1954; *ROWJ*, **2** (1), 1955], with an attempt to re-examine the structure and fluctuations of the Kuroshio carefully on a basis of more reliable data collected by recent regular cruises. The data from Kuroshio off Shionomisaki indicate a seasonal fluctuation in volume transport and kinetic energy of the stream there, with maximum in early spring and fall, and minimum in winter and early summer, based on data from December, 1951 to November, 1953. Masuzawa found that the rate of southward shift of the

stream axis which occurred in July, 1953, was three miles per day. From the monthly mean temperature along the C-line (38° 15′ N., 142° E. to 151° E.) during six years, 1948 to 1953, he studied the presence of Kuroshio warm waters in two separate locations of which the offshore one displaced westwards from summer to fall. A reliable example of seasonal fluctuations of the Kuroshio in the region of the C-line was for the first time obtained from seasonal observations carried out in 1954. The features noted remarkably resemble those of the Gulf Stream reported by Fuglister *et al.* Masuzawa appears to consider that the more detailed survey on the Norpac expedition in the summer of 1955 has revealed even more resemblance of the Kuroshio to the Gulf Stream in their fine structure. In 1955, Masuzawa published three papers on the structure of Kuroshio based on the past data as well as recent data [*OM*, **7**, 1955; *ROWJ*, **2** (2), 1955; *OM*, **7** (2), 1955]. The most recent one gives some description of the structure of Kuroshio further to the east of Japan, approximately to 160° E., on the basis of data obtained by the Norpac expedition. One of the recent works of S. Moriyasu which dealt with the variation in the oceanographic conditions in the Enshu-nada appears to confirm the northward shift of the stream axis of Kuroshio and of the center of cold water mass with a rate of 6 miles per day. This estimate was based on two series of observations made with an interval of ten days in October, 1954. Displacement of isopycnals during this time interval appears to imply that upwelling occurred in the northern region of the cold water mass, and sinking in the southern region [*JOSJ*, **11** (2), 1955].

In 1956, Moriyasu discussed the oceanographical conditions south off Honshu during 1954, with particular attention to the fluctuation of the cold water mass in Enshu-nada, for which the corresponding fluctuation of the strength of upwelling is indicated to be responsible [*OM*, **7** (2), 1956].

H. Kawai has published a detailed work on the oceanographic structure of the Polar Frontal Zone in the waters to the northeast of Japan, based on more detailed observations during recent years. The Polar Frontal Zone consists of two narrow bands of strong eastward currents separated from each other. Kawai called the northern band the "Oyashio Front," and the southern the "Kuroshio Front." The fluctuation in the position of each front was discussed (*TRFLB*, **4**, 1955; *TRFLB*, **5**, 1955). K. Kajiura has worked extensively on physical oceanography in the Japan Sea, from a great quantity of data amassed up to the present in the area. He found interesting characteristics of annual variation in each of the branches of the Tsushima Current. A close relationship between the fluctuation in the intensity of the warm current and that in the cold water masses was pointed out (unpublished, 1954).

T. Ichiye has published a series of papers on the variation of the oceanic circulation. In most of these works, he attempted to account theoretically for observed meanders of isotherms in the Polar Front region (*OM*, **5**, 1954). He worked theoretically on various possible mechanisms which might be responsible for generation of the conspicuous cold water mass off Enshu-nada, and his results indicate that a meandering of the Kuroshio main current appears to be responsible for the formation and that the meander is due to prevailing winds in winter and to the topographic disturbance around the Ogasawara ridge. In this connection, he showed from observed data that the water mass in this cold water came from subsurface depths due to upwelling [*GM*, **26** (4), 1955]. In another paper, Ichiye discussed an interrelation between fluctuation in cold water mass and that in the main current of the Kuroshio, and, in addition, on the upwelling process of cold water mass [*GM*, **25** (3-4), 1954]. He discussed an analogy of the observed variations in Kuroshio off Shionomisaki to those of the jet stream in the atmosphere [*OM*, **6** (1), 1954].

Ichiye discussed a possible origin of the intermediate water in Kuroshio [*ROWJ*, **2** (2), 1955]. He published a paper concerning the dynamic interpretation of the occurrence of the cold water region on the left edge of the Kuroshio. [*GM*, **26** (4), 1955]. He also published a series of papers on dynamics in the polar front region in 1956. First, he gives a theory of formation, growth and decay of the vortex in the region [*OM*, **7** (2), 1956]. Second, an observed fact that the warm water extended to the north is interpreted by a mechanism of the surface drift by southerly wind [*OM*, **8** (1), 1956]. His third and fourth papers, concerned with a mechanism of the cold water mass on the northern boundary of the Kuroshio, give somewhat detailed descriptions of the cold water mass observed during May, 1955, and possible causes of such occurrence [*OM*, **8** (1), 1956]. In connection with the vortices in the polar front region, K. Kitano experimentally reproduced these eddies in a model tank and classified them into several types according to their characteristics [*JOSJ*, **12** (4), 1956].

Variations of the conditions in the Polar Front were also studied by J. Fukuoka based on oceanographic and meteorological informations for 1950 to 1953, and on surface water temperature from 1933 to 1953 [*OM*, **6** (4), 1955]. By use of a current meter designed by him, T. Nan'niti attempted to observe a current at a rising state when surface wind was developing [*MGP*, **4** (2), 1953], and also found a fluctuation in the current speed with a period of approximately 1.5 hours in a shallow water near a coast [*MGP*, **5** (1), 1954].

K. Yoshida returned to Japan in November of 1954, after two years' absence during which time he worked at the Scripps Institution of Oceanography on three papers: Physical oceanography in the Marshall Islands area (*Geological Survey Professional Paper* 260-*R*, 1955); Circulation in the upper mixed layer of the Equatorial North Pacific; and A new method for estimating upwelling with an example in the California Current region (in press). In the last work, he (with Han-Lee Mao) obtained somewhat smoothed features of vertical motion in the region by a method using observed density distributions and found remarkable agreement with the indications from other sources of data. As a continuation of this work, Yoshida published a theory [*ROWJ*, **2** (2), 1955] which appears to confirm the observed fact, revealed by a recent increased density in nearshore stations, that a coastal upwelling may take place within a narrow strip close to the coast of California, practically limited at distances less than 50 to 100 km. from the coast. The speed of this upwelling is measured by wind speed, and the variations in surface currents associated with upwelling were found consistent with observed conditions. He attempted to account for an example of seasonal variation in surface oceanic circulation, revealed from the data off the California coast, by giving a simple model in which a rearrangement of density through wind-induced vertical motion is essential to the changes. Emphasis was placed on the point that variations in currents are in quasi-stationary balance with a pressure field which varies as an integral effect of winds, so that a possibility of a quantitative prediction might be suggested [*JOSJ*, **11** (3), 1955].

In 1956, Yoshida published a theory of pressure change of the two-layer ocean in response to the variable wind stress applied at the surface. This paper is concerned with the variations of periods longer than several days and of wavelength longer than ten kilometers. The relative importance between the barotropic response and the baroclinic response of the ocean to wind variations of various scale is examined [*JOSJ*, **12** (4), 1956].

In relation to fisheries conditions, circulation and its fluctuation have been actively investigated by M. Uda. Uda made a study of the subtropical convergence in the northwestern Pacific, and found discontinuous distributions of water temperature, salinity, turbidity and currents, particularly in winter and spring, in the region. He found this discontinuity corresponds to a border line of the marine biological environment and also to the southernmost fishing grounds of whales, albacore, and so on [*ROWJ*, **2** (1), 1955]. Recently Uda worked on the fluctuation of the Oyashio Current in relation to the atmospheric circulation and to the distribution of the dichothermal waters in the North Pacific [*ROWJ*, **2** (2), 1955]. He indicated that the anticyclonic eddies in the frontal zone of water masses in the adjacent waters of Japan correspond to the notable whaling grounds (*Sc. Rep. Whale Res. Inst.*, **9**, 1954). He found that a marked variation in the water temperature in the waters adjacent to Japan took place in the passage of typhoons, based on numbers of observed data. He ascribed these changes to turbulent mixing and horizontal transport of water masses induced by those storms (*AIOP Proc. Verb.* **6**, 1955).

A theory of a transient state of upwelling and coastal current was published by Yasukazu Saito. This is an extention of Hidaka's work on the steady-state solution for the homogeneous ocean model to a transient state [*TAGU*, **37** (1), 1956]. During his stay at Florida State University, M. Hanzawa gave some brief comments on water-mass characteristics and on short-range changes in oceanic conditions in the Kuroshio during the period from January to June, 1952. Comparison between the Kuroshio and the Gulf Stream was also discussed (*Florida State University, Technical Report* No. 3, 1955).

Hanzawa also published a short note on application of Fukuoka's theory of the variation of the conditions in Polar Front to the practical prediction [*OM*, 7 (2), 1956].

N. Iwata, in a discussion of the recent theory of turbulence, derived the spectrum of the velocity fluctuation in Kuroshio between Ito and Hachijo Island based on tide gauge records [*JOSJ*, **12** (2), 1956].

Other Contributions to Circulation Problems. D. Shoji (*HB*, **17**, 1955) indicated that measurements of currents by *GEK* agreed with the results

by other means such as by current meters and by dynamic computations. M. Yasui [*ROWJ*, **2** (2), 1955] devised a useful method for a rapid determination of the dynamic depth anomaly in the Kuroshio area. He uses temperature alone for this simplified dynamic computation and found its practical significance.

A theoretical study was made by Yukimasa Saito on the currents near the Polar Front under the assumption of the conservation of vorticity (*JIP*, **2**, 1954).

Based on the data from four cruises during the period March to July, 1950, in a boundary area of the Kuroshio off Nozima-zaki, T. Hirano [*JOSJ*, **8** (3-4), 1954] determined velocity of the southward flow of the Oyashio water along the Pacific coast and also determined lateral diffusivity. He also discussed the circulation of the water in Hamana Lake (*JSSFB*, **20**, 1955).

Hydrography

The stratification of water masses in the north Japan Sea (west of the Tsugaru Straits) and some other features were discussed by M. Akagawa based on the observations in 1950 to 1953 [*JOSJ*, **10** (4), 1954; *JOSJ*, **11** (1), 1955]. I.Yamanaka worked on the data collected in the Japan Sea during spring to summer in 1959, and discussed meandering of Tsushima Current and the water masses in the areas.

M. Nagai [*KK*, **6** (2-4), 1954] examined annual variations in temperature and salinity of the waters in the Goto-nada. Hydrographic structure in the Tsushima Current area was discussed by T. Tsujita with special reference to its fisheries importance (*Bull. Seikai Regional Fish. Res. Lab.*, **1**, 1954; *ibid.* **6**, 1955; *JOSJ*, **10**: 3, 1954). One of Tsujita's works is concerned with red tides.

I. Nakayama made some remarks on variations of water temperature in the Japan Sea and on the influence of the river water upon the oceanographic condition in the western part of Wasaka Bay [*KJ*, **8** (6), 1956; *KJ*, **8** (7), 1956]. He further discussed the upper limit of the cold water proper in the Japan Sea [*OM*, **8** (1), 1956]. Mi. Miyazaki attempted to apply Hidaka's theory for a determination of convergence and divergence in the ocean from wind data to the Japan Sea.

S.Mishima and S. Nishizana described the results of oceanographic investigations in Aleutian Waters and the southern Bering Sea in the early summers of 1953 and 1954 (*Bull. Faculty Fish. Hokkaido Univ.*, **6**, 1955).

The data collected in our northern seas to the north of 42° N. during the past sixty-six years were published in a volume, issued in 1954. N. Watanabe [*JOSJ*, **11** (3), 1955] worked on a fluctuation of surface temperature in the northern ocean based on observations in 1953.

The oceanographic observations over the area of the northwestern Pacific, especially over the Kuroshio regions, have been carried out with great interest. The boundary zone between the Oyashio and Kuroshio, and the waters off Sanriku coasts have been surveyed by the Hakodate Marine Observatory. K. Hata and M. Torii [*CI*, **38** (1-2), 1954] and J. Sugiura [*KH*, **3** (3), 1954] described the observed results.

Sugiura computed the average volume transport of the water in the areas [*OM*, **6** (4), 1955; *OM*, **7** (1), 1955] and also studied the current branches in the Oyashio region near Hokkaido (*JOSJ*, **12**: 4, 1956). S. Hikosaka and R. Watanabe studied the oceanographic conditions in Kuroshio region to the south of Honshu, with special reference to the cold water mass in Enshu-nada (*HB*, Spec. **17**, 1955).

T. Ichiye published papers on the distribution of oxygen and its seasonal variation in the adjacent seas of Japan (*OM*, **6**, 1954). He discussed extensively the distribution of oxygen in various areas, especially the horizontal exchange of oxygen due to mixing in the Polar Front region, and annual variation in oxygen content in the Kuroshio areas. He derived a method to estimate the volume transport and the rate of displacement of main currents of Kuroshio from oxygen distributions. He applied a hydrodynamical theory of vortex behind an island, and compared the result with observations (*ROWJ*, **2**, 1954). He discussed the annual variation of chlorinities at the upper 50 m. depths in the Kuroshio [*OM*, **7** (2), 1956].

J.Fukuoka and I.Tsuiki discussed on a variation of chlorinity in the Kuroshio area [*OM*, **6** (1), 1954]. Fukuoka gave a discussion on water masses by use of temperature, salinity and density over the large area of 10° to 45° N., 130° to 160° E. [*ROWJ*, **2** (2), 1955].

K. Hishida studied statistically the variation of the specific gravity and the temperature of the coastal water all around Japan and also discussed the relation of the variation to that of the oceanic water [*OM*, **7** (1), 1955]. Seto Inland-Sea has been regularly surveyed by the Inland-Sea Regional Fisheries Research Laboratory, and reports and papers have been published in the Bulletin of

their laboratory and in the report of Inland-Sea Fisheries co-operative investigation during the years. Y. Ojima and M. Hisaoka found a periodicity in salinity and temperature of water in the Seto Inland-Sea of which the periods are 3, 4 to 5, and 6 years.

Z. Yasui and Matsuno discussed the circulation in the China Eastern Sea based on oceanographic observations made in 1951 and 1952 [*ROWJ*, **1** (1), 1953].

M. Ishino described the results of a hydrographic survey in the Equatorial Pacific, the South China Sea, and the Formosa-Satsunan Kuroshio region [*ROWJ*, **2** (1), 1955]. The hydrography in the Marshall Islands area were described by S. Hori and S. Yoshida on the basis of *Shunkotsu Maru* observations during May-June, 1954 (*HB*, Spec. **17**, 1955).

Other Activities on Dynamic Processes

Estuarine Oceanography. K. Takano derived theoretical distributions of velocity and salinity of water off the mouth of a river [*JOSJ*, **10** (3), 1954].

In 1955, T. Ichiye gave suggestions on the points governing the condition of the estuarine circulation [*JOSJ*, **11** (4), 1955]. He examined theoretically the effects of the earth's rotation, mixing, and inertia. In the same year, Takano made a study on the effects of the earth's rotation and lateral mixing on the behavior of the seaward river flow off the mouth of a river. [*JOSJ*, **11**(4), 1955].

Theory of the Upper Mixed Layer. Yu Saito made a theoretical approach to the variation in density stratification by taking account of compressibility of water [*JIP*, **1**(1), 1954].

Biology Dynamics. A.Okubo wrote on the decomposition of sinking remains of plankton organisms and its relation to nutrient liberation [*JOSJ*, **10** (3), 1954; *JOSJ*, **12** (2), 1955]. T.Ichiye attempted to account for the observed daily fluctuations in plankton populations by assuming a relation between predator and prey as population dynamics (*OM*, **6**, 1954).

Results from the Shunkotsu Maru Survey, and Diffusivity. Based on the results of the *Shunkotsu Maru* survey over the waters around the Bikini Atoll in May to June, 1954, Uda [*Kakagu*, **24** (12), 1954] and H. Miyoshi (*ibid.*) discussed circulation and pollution of water in the region. Uda discussed the radioactive pollution of the tuna fishing grounds. Miyoshi appeared to have found the presence of a weak eastward current around 15° N. and the presence of pollution of water below thermocline to the west of Bikini, which was probably due to sinking calcite particles. He also estimated the coefficient of vertical eddy diffusivity to be 5 cm^2/sec from those data [*ROWJ*, **2** (2), 1955; *Suisancho Chosakenkyubu*, 1955; *Japan Science Congress*, 1955; Researches in the Effects and Influences of the Nuclear Bomb Test Explosions, *Science Council of Japan*, 1956].

Upwelling, and Vertical Circulation. In addition to works on upwelling which were mentioned before (Hidaka, Ichiye, Yoshida), a few papers appeared on this problem. A theory on upwelling induced by a circular wind system was made by Hidaka and Y.Akiba [*ROWJ*, **2** (1), 1955], and S. Hikosaka wrote three papers on upwelling, especially in the cold water mass, from observed data as well as theory [*HB*, Spec. **15**, 1954; *HB*, **43**, 1954; *ROWJ*, **2** (1), 1955].

M. Nakano discussed vertical circulation caused by winds, with special reference to its bearing on submarine geology and topography. He pointed out that characteristics of the bottom, especially the size of the bottom sands, are essential to the process [*ROWJ*, **2** (2), 1955].

Ichiye wrote a short note on the vertical current in the ocean with a theoretical model for the ocean in equatorial regions [*OM*, **7** (1), 1955].

Flood. T. Kinoshita worked on flood flow in a river by solving a nonlinear equation numerically. The result may suggest the validity of dynamical factors involved and a practical method for flood prediction (*Sori-fu*, Shigen Chosa-Kai, Sui-144, Kasen-7; 1955). He further worked on a programing of numerical computations on flood flow for the relay computer (*Resource Council of Prime Minister*, Sui-190, Kasen-15′, Sui-4, Suimon-3; 1956).

Physical Properties of Sea Water

Sea Ice. The activities in studies of sea ice have been continued by Fukutomi, K. Kusunoki and T.Tabata at the Low Temperature Science Institute of the Hokkaido University. Those studies have covered various phases of the sea ice problem and are steadily in progress. Their approach has been made by field survey in the areas around Hokkaido, experimental studies such as on visco-elastic constants of sea ice [*ROWJ*, **2**, 1955; *JOSJ* **11** (4), 1955] and by improving the method of sampling sea ice (*TK*, *A*, **12**, 1954; International Commission on Snow and Ice, IUGG, Rome, 1954). Horizontal and vertical distributions

of chlorinity of sea ice have been observed by Kusunoki [*ROWJ*, **2**, 1955; *JOSJ*, **11** (4), 1955]. The relationship between the beginning date of freezing and air temperature has been derived by Fukutomi (*TK*, **11**, 1953) from a theory whose applicability was shown practically satisfactory (*TK*, **13**, 1954). Y. Suzuki [*ROWJ*, **2**, 1955; *JOSJ*, **11** (3), 1955] published a preliminary report of the observations of ice crystals formed on the sea surface. K. Kawakami reported the general conditions of sea ice observed during 1954 at various points along the coast of Hokkaido (*HB*, Spec. **17**, 1955). The same number of the *Bulletin* contains the report on the conditions of sea ice in Ryoto Kaiwan on the basis of observations during 1938-1942.

Sound. M. Outi (*Bull. Kyoto Gakugei Univ.*, **3**, 1953; *ibid*, **5**, 1954) published two papers on sound in sea water. The first is concerned with sound velocity in sea water, and the second is with the SOFAR structure in the Japan Sea.

Optics. K. Hishida studied the turbidity of sea water from a physical point of view, especially in its relation to radiation energy. He discussed its fluctuation based on observations in Wakasa Bay, and pointed out its relation to oceanographic and fishing conditions and also to meteorological conditions (*JOSJ*, **9**, 1954; Hishida and Y. Honda, Tsushima Current, *Kaihatsu Chosa Hokoku*, **1**, 1954).

A theory of transparency of sea water was attempted by T. Nan'niti. He suggested that a "turbidity factor," a ratio of total extinction coefficient to molecular scattering coefficient, could represent a good measure of turbidity (*MGP*, **3**, 1953; *MGP*, **5**, 1954).

T. Sasaki and his collaborators computed the coefficients of absorption and of scattering from the measured brightness and visibility of an object in a parallel beam by a headlight bulb (*Bull. Jap. Fisher. Research Laboratory*, **6**, 1954). T. Sasaki, N. Okami, S. Watanabe and G. Oshima investigated optical properties of the water in the Kuroshio current by means of a high sensitive under-water photometer [*ROWJ*, **2** (2), 1955]. They described the structure and method of operation of an under-water camera which they devised and gave some recent applications [*JSRI*, **49** (1): 388, 1955]. The same authors published the results of measurement of angular distributions of light in the sea with an underwater observation chamber [*JSRI*, **49** (1): 387, 1955].

T. Hanaoka and his collaborators studied the relation between underwater illumination and suspended matter, and introduced a quantity "suspension factor" which is very significant to the measurement of the particle size of suspended matter (*JSSFB*, **22**: 4). In this connection, D.L. Fox's method was improved in a form suitable for the measurement of suspended organic matter in the shallow sea (*JSSFB*, **22**: 4).

Foaming. T. Abe has published a series of papers on foaming of sea water. This interesting problem has been attacked by laboratory experiments and by theory as well. His main interest so far has been in discussions on the mechanism of the decay of bubbles and their size distribution in the foam layer of sea water [*KH*, **3**, 1953; *JOSJ*, **9**, 1953; *ROWJ*, **1** (2), 1953; *JOSJ*, **10**, 1954; *KH*, **3**, 1954; *MGP*, **5**, 1955; *ROWJ*, **2** (1), 1955; *JOSJ*, **11**, 1955; *MGP*, **6** (1), 1955].

As mentioned before (see WAVES), T. Abe examined the relation between the wind waves and the surface water temperature by using open sea data in connection with his study of foaming.

DSL. Extensive studies of the deep scattering layer (DSL) have been carried out by the group at the Tokyo University of Fisheries, and they are presented in the *Journal of the Tokyo University of Fisheries*, **42** (2), 1956. The contributions contain the study of DSL by ultrasonic wave and the result of model experiments of reflection of ultrasonic wave at a discontinuity of temperature or density of water by T. Hashimoto and Y. Maniwa.

T. Sasaki, S. Watanabe, G. Oshiba and N. Okami found certain relationships between the DSL and under-water illumination. Based on the observations, Y. Komai and Y. Matsuye examined the relationship between the occurrence of DSL and the distributions of plankton. K. Ozawa and J. Ihara discussed the diurnal variation of the depth and the frequent occurrence of DSL in the central part of a vortex. M. Uda gave summary reports of the researches on DSL which were carried out by the research group during 1952-1955. The relation between DSL and the fishing grounds is discussed. N. Watanabe and M. Ishino are the co-authors of one of the papers.

INSTRUMENTS

T. Nan'niti devised a current meter using a phototube to record current velocity in the sea [*MGP*, **3** (4), 1953; *MGP*, **4** (2), 1953; *MGP*, **5**(1), 1954]. Some experiments have been made with this current meter. He obtained information

on drift currents at the rising stage, and fluctuations in currents were also measured in shallow waters. Nan'niti designed a new type of current meter [*MGP*, **5** (3-4), 1955] recently which would be quite useful for obtaining a detailed structure of the current in the sea. This is composed of an underwater portion and a record on deck, with a three-fold rubber-covered cable of 50 meters in length to connect them.

Current speeds are recorded by use of closing the electric circuit in accordance with the frequency of rotation of the propeller, and its directions are measured by a distribution of brass balls dropped into a magnet box. Furthermore, he devised a new method of recording and analyzing information on current speeds obtained by the above current meter. The instruments are composed of an electric recorder, frequency counter, and correlation meter, (Nan'niti and T. Furuhata, in press). Another of his contributions was a new plastic water sampler which was fitted with a stem mercury-in-glass thermometer in its inner side for use in coastal waters (*MGP*, **5**, 1954).

S. Ishiguro and his colleagues, A. Fujiki and M. Nagata, at the Nagasaki Marine Observatory, made a number of contributions to oceanographic instrumentation, particularly to wave-measuring devices. They devised improved types of the previously reported electronic recorders for sea wave pressure [*JOSJ*, **12** (1), 1956].

Another important contribution by S. Ishiguro and his colleague was development of an analytical method for measuring the oscillations of water in bay or lake, using an electric network and an electronic analogue computer [*KK*, **6** (2-4), 1954; *JOSJ*, **11** (4), 1955]. They proposed a new method for analysis of transient phenomena of a hydrodynamic system having a free surface and use the case of Nagasaki Bay as an example. The main operation of analysis was carried out by an electric network being analogous to the hydrodynamic system, and by an electric analogue computer designed for this purpose.

S. Moriyasu wrote a note on theoretical consideration of load which may act on hydrographic winches [*KJ*, **8** (3), 1956].

By use of the undersea observation chamber "Kuroshio," photographic study of suspended matter and plankton in the sea was made by S. Nishizawa, M. Fukuda and N. Inoue (*Bull. Facult. Fish.* Hokkaido Univ., **5**, 1954).

K. Hata derived an empirical formula for determining the depth of a sampling bottle from information on wire length and wire angle above the sea surface [*JOSJ*, **11** (2), 1955]. Effects of tides on the magnification of a wave recorder using a stand-pipe were discussed by S. Unoki. He suggested that a wave recorder of this type is not suitable for use at stations with a large tidal range [*JOSJ*, **12** (3), 1956].

Two papers on *GEK* were published. R. Higano and D. Shoji tested the electrodes of *GEK* in the laboratory and ascertained that the electrodes did not polarize in sea water (*HB*, Spec. **17**, 1955). D. Shoji also derived, with his collaborators S. Hori and S. Yoshida, the formula for the "droop" correction which must be added to the actual observation as two electrodes are not in a horizontal plane when they are towed by a ship (*HB*, Spec. **17**, 1955).

Sea Water

Y. Miyake and his collaborators in the Meteorological Research Institute have shown their activities in studies of chemistry of sea water.

K. Saruhashi applied Conway's micro-diffusion method to the analysis of the total carbon dioxide in the sea water. She deduced a theoretical relation between pH and the total carbon dioxide in sea water (*MGP*, **3**, 1953; *JOSJ*, **10**, 1954). In the diurnal variation of dissolved oxygen in surface water, the maximum occurs at about 4 P.M. and the minimum at 6 A.M. or so. The difference between the maximum and minimum depends upon the solar radiation, temperature and the amount of phytoplankton.

Miyake, Sugiura and Kameda worked on the distribution of radioactivity in the sea around Bikini Atoll in June, 1954, and found that radioactivity was present in the upper 200 m. layers (*MGP*, **5**, 1954). Miyake and Sugiura made the radiochemical analysis of radionuclides in the sea water collected near Bikini Atoll, and detected Y-91, Ce-141, Ce-144, Ru-103, Ru-106, Zr-95, Nb-95, Sr-89 (*MGP*, **6**, 1955). Miyake and his collaborators estimated productivity in coastal waters by means of the radio-carbon C^{14} (*MGP*, **5**, 1954). Miyake and Kameda worked on designing of the automatic titrimeter for the chlorinity determination of sea water (unpublished).

R. Fukai has made critical studies of the analytical method for determining minor chemical constituents in sea water. He studied the analytical method for phosphate and for silicate in sea water by using Beckman's Quartz spectrophotometer, and for nitrate-nitrogen by using the

reduced strychnine reagent (*JOSJ*, **10**, 1954; *JOSJ*, **11**, 1955). He also established an analytical method for ammonia using the reaction between ammonia and hypobromide (*JOSJ*, **11**, 1955). He has also reported on distributions of minor chemical constituents in the waters of the equatorial North Pacific, of the Kuroshio region and in the waters adjacent to the Aleutian Islands [*Chem. Soc. Jap. Bull.*, **26** (9), 1953; **27** (7), 1954; **28**, 1955].

Y. Morita determined distributions of copper and zinc in the Kuroshio surface waters, and also found that both elements increase their amount gradually below the 200 m. level in the Bays of Sagami and Suruga.

He made measurements for the above two elements also in surface waters in various coastal regions, and in Tokyo Bay he found that their content decreases toward the mouth of the bay (*Journal of Earth Sciences*, Nagoya Univ., **3**, 1955).

M. Ishibashi, T. Shigematsu and Y. Nakagawa determined the amounts of selenium, tungsten, and molybdenum in sea water from water samples collected off Shirahama, Wakayama Pref. (*Bulletin of the Inst. Chemical Res.*, Kyoto Univ., **32**, 1954). Ishibashi and T. Hara determined the amount of cesium dissolved in sea water (*Bull. Inst. Chem. Res.*, Kyoto Univ., **32**, 1954). Ishibashi and S. Higashi determined the amount of thorium in sea water off the Shirahama coast (*Bunseki-Kagaku*, **3**, 1954). Y. Matida discussed the cycles of phosphorus and nitrogen in Tokyo Bay (*JSSFB*, **19**, 1953; **20**, 1954). He studied the source and the fate of fluorine in water of Tokyo Bay [*JOSJ*, **10** (2), 1954], and, in collaboration with his colleagues, worked on water pollution in the northern part of Lake Kitaura by the waste from starch works [*The Agriculture*, **2** (1), 1954]. T. Okuda has published a series of papers on studies of the soluble nutrients in bay deposits, based on examinations of the diffusion of soluble nutrients to sea water from mud (*Tohoku-Kaiku Regional Fisheries Research Inst.* Report No. 4, 1955). Okuda and S. Sato worked on the bottom materials of Matsushima Bay from a viewpoint of marine resources of this bay (*ibid.*, 4, 1955).

Ishibashi, K. Emi, H. Kataoka and S. Kitadani presented a new method for determining boric acid by barium saccharate [*ROWJ*, **2** (2), 1955].

H. Makimoto, E. Haeda and S. Era studied the relation between chlorinity and silicate concentration of water observed in some estuaries [*ROWJ*, **2** (1), 1955].

S. Takashima, Y. Hagino and G. Hashizume performed the standard measurement of K and Na mixtures, and studied the accuracy of the method by the application of X-ray spectrophotometer to determine the most accurate technique for the analysis of sea salts.

Submarine Geology

H. Niino gave a description of a large sand-pipe dredged from the sea floor off California. Such a sand-pipe, which looks like the hole made by some kind of crab, is often dredged from the sea floor around the Japanese Islands [*J. Sediment. Petrol.*, **25** (1), 1955].

Niino, N. Nasu and R. H. Parker compiled the data on bottom sediments along the coast of the Gulf of Mexico made by Japanese fishing boats in 1936 and 1937. The results show the existence of coarse sediments at the depth around 50 meters [*TUFJ*, **42** (1), 1956].

Niino and T. Kumagori wrote a preliminary report on the new bank at the southern end of Emperor Sea Mount [*TUFJ*, **42** (1), 1956]. Niino and K. Ozawa made a study of the visible figures of the bottom which resembles those of DSL, based on the observations in the region between Shimonoseki and Ube and in the sea along the coast of Nagasaki Prefecture [*TUFJ*, **42** (2), 1956].

M. Hoshino discussed the relation between abnormal distribution of blue mud and fishing ground [*JOSJ*, **12** (4), 1956]. S. Uyeda analyzed the shallow water deposits in some prefectures along the coast of Japan and determined their chemical constituents [*JOSJ*, **12** (3), 1956].

An extensive study on beach erosion near Omori-hama, Hokkaido, was published by R. Komukai (*Suirobu Hokoku*, **13**, 1956). A. Moki described the submarine topography in the eastern and western part of Sagami Bay in detail, use being made of recent sounding results (*HB*, Spec. **17**, 1955). Nasu finished his study at the Scripps Institution of Oceanography in 1955 and published a paper partly prepared at Scripps on his return to Tokyo. The work was on the particle size distribution of the bottom sediments along the Gulf of Sagami. The processes of formation of beach and dune sands were discussed from hydrodynamical as well as sedimentological viewpoints (*Jour. Fac. Sci., Univ. Tokyo*, Sec. II: 10, 1956).

R. Morimoto, R.L. Fisher and Nasu made bathymetric measurements of the Bayonnaise Rocks and their surroundings, and also described

the petrography of the rocks of which samples had never been collected before. The rocks are hypersthene-augite-anorthite basalt resulting in the relatively high CaO and comparatively low SiO_2 values [*Proc. Japan Academy*, **21** (10), 1955].

H. Kuno, R.L. Fisher and Nasu presented petrographic descriptions of the rock fragments and pebbles dredged from the ocean bottom at 5,000 meters near Jimmu Seamount, northwestern Pacific. The results suggest the transportation of those debris by icebergs during the pleistocene age (*Deep-Sea Research*, London, **3**, 1956).

ABBREVIATIONS

The following abbreviations are used in the text for the names of the publications:

AIOP *Association Internationale d'Océanographic Physique*

CI *Chuokishodai Iho, CMOZ*

CR *Comptes Rendus*

DPRIB *Bulletin of the Disaster Prevention Research Institute*, Kyoto University

ERIB *Bulletin of the Earthquake Research Institute*, Tokyo University, Tokyo

GM *Geophysical Magazine*, Central Meteorological Observatory, Tokyo

HB *Hydrographic Bulletin* (*Suiro Yoho*), Japanese Hydrographic Office, Tokyo

HFLB *Bulletin of Hokkaido Regional Fisheries Research Laboratory*, Yoichi, Hokkaido

JIP *Journal of the Institute of Polytechnics*, Osaka City University, Osaka

JJG *Japanese Journal of Geophysics*, Tokyo

JMR *Journal of Marine Research*, U.S.A.

JNSJ *Journal of Nautical Society of Japan.*

JOSJ *Journal of the Oceanographical Society of Japan*, Tokyo

JSRI *Journal of Science Research Institute.*

JSSFB *Bulletin of the Japanese Society of Scientific Fisheries.*

KJ *Chuo Kishodai Kenkyu Jiho* (Journal of Meteorological Observatory, Tokyo)

KH *Kaiyo Hokoku* (The Oceanographical Report of Central Meteorological Observatory)

KK *Kaiyo to Kisho* (Oceanography and Meteorology), Nagasaki Marine Observatory, Nagasaki

KMOM *Memoirs of the Kobe Marine Observatory*, Kobe

MGP *Papers in Meteorology and Geophysics*, Meteorological Research Institute, Tokyo

MMOR *Maizuru Marine Observatory Report*

NMOR *Nagasaki Marine Observatory Report*

OM *Oceanographical Magazine*, Central Meteorological Observatory, Tokyo

ROWJ *Records of Oceanographic Works in Japan*, Japan Science Council, Tokyo

SRGU *Science Reports of the Gumma University*

TAGU *Transactions, American Geophysical Union*, U.S.A.

TK *Teion Kagaku* (Low Temperature Science), a publication in Japanese, edited by the Low Temperature Institute, Hokkaido University, Sapporo

TRFLB *Bulletin of Tohoku Regional Fisheries Research Laboratory*

TUFJ *Journal of the Tokyo Fisheries University*, Tokyo

US *Umi to Sora* (Sea and Sky), published by the Marine Meteorological Society, KMO, Kobe

NOTE ON THE ACTIVITIES OF THE OCEANOGRAPHIC SECTION OF THE INSTITUT FRANÇAIS D'OCÉANIE, 1953 - 1957

F. BUGNICOURT

Institut Français d'Océanie, Nouméa, New Caledonia.

1953-1955 LAGOON RESEARCHES

In the absence of a research vessel, oceanography, the work of the oceanographer apart from problems of internal organization, was limited to lagoon studies.

In biological oceanography, the inventory of the species constituting the ichthyological fauna of the lagoon has continued and about 120 species have been identified, pending a later period during which an evaluation of the possibility of the lagoon for the development of a small local fishery may be followed up.

In the meantime, Mr. Rotschi, physical oceanographer, arrived; and a second-hand vessel was purchased. The staff have devoted themselves to a great extent to organizational problems, the greatest of which was the refitting and equipping of the vessel. The vessel, renamed *Orsom III*, commenced work at the end of 1955, and the oceanographic program of the IFO could then be reasonably attempted in proper manner. Between times, a second oceanographic biologist, M. Gail, was attached to IFO and he undertook research in the biology of Trochus, which was, however, interrupted by his tragic disappearance at the beginning of 1957.

1956-1957 PELAGIC RESEARCH

The activities of *Orsom III* were devoted to the routine performance of the programme of hydrological and biological exploration in the area adjoining the New Hebrides, approximately 250 miles east from New Caledonia. The objective of this exploration is to define the physico-chemical environment in relation to the fishing results obtained by trolling and long-lining and to an evaluation of the Tuna resources.

The vessel is equipped to make hydrological investigations to a depth of approximately 2,000 metres; the following analyses and routine measurements can be undertaken on board: salinity, phosphate, oxygen, pH. At the same time, regular plankton tows are taken, and in 1958, the inclusion in the programme of the measurement of Carbon - 14 is anticipated. From the beginning of June, 1957, a carefully planned long-lining programme has been instituted.

Up to the present, the vessel has maintained a schedule of two voyages of ten to fifteen days each quarter, one eastward from New Caledonia and towards the New Hebrides, the other westward from New Caledonia. However, one must exclude, during 1956, three months required for overhaul, and two months devoted to participation in the Equapac cruises which have led *Orsom III* from the New Hebrides to the Gilbert Islands.

The first results of these activities are being edited or circulated.

NEW ZEALAND OCEANOGRAPHY SINCE 1952

J.W. BRODIE

New Zealand Oceanographic Institute, New Zealand.

Until 1954, oceanographic research has been carried out by the Oceanographic Observatory which was formed in 1949 as a branch of Geophysics Division, D.S.I.R. under the late W.M. Jones. The work done was primarily concerned with hydrography and wave dynamics, but in 1954 T.M. Skerman was appointed as biologist on H.M.N.Z.S. *Lachlan* to replace Lieut. B.M. Bary, R.N.Z.N. of Defence Scientific Corps, thus allowing *Lachlan* to continue effectively as a part-time research vessel. The cooperation in this matter of the New Zealand Naval Board and of the various commanding officers of *Lachlan* has been very helpful to New Zealand oceanography in its early stages.

The New Zealand Oceanographic Committee, formed in 1950, has continued to operate as an advisory body of the Council of Scientific and Industrial Research. Representatives of the Navy, D.S.I.R., Marine Department, the four University Colleges, Portobello Marine Biological Station, Auckland and Dominion Museums, and the Meteorological Office serve on this committee, one of whose functions is to coordinate, correlate, and assist oceanographic work and to sponsor publication of results.

In July, 1954, the present New Zealand Oceanographic Institute incorporating the Observatory, was formed in Wellington under J.W. Brodie. The professional staff has since been expanded to a total of ten, including three physicists, four biologists, two geologists, and one bacteriologist. In 1956, the increase in staff necessitated a move to new premises in Thorndon Quay; provision is being made for a permanent building on the waterfront at Evans Bay. A research vessel, H.M.N.Z.F.A. *Tui* was refitted and commissioned in 1956 by the Navy for the joint use of the New Zealand Oceanographic Institute and the Naval Research Laboratory. This ship, which has cabin and laboratory accommodations for six scientists is fully equipped with oceanographic winches, as well as radar, echo sounding, and other modern navigational aids. Two major series of cruises were carried out in the winter of 1956 and the summer of 1956-57. These have encircled the whole of New Zealand with a pattern of hydrographic and plankton stations which will serve as a base for further, more intensive studies. Among the preliminary results, the subtropical convergence was found not to agree with previous ideas. In the winter cruise it lay obliquely between a point to the north of Chatham Island and another well to the south of Stewart Island.

Individual research projects are as follows:

Dr. R. W. Burling has conducted research into the relationship between the velocity and duration of winds and the waves generated by them. He is also working on the analysis of drift card returns and on southern ocean hydrology.

D.M. Garner is investigating the general physical structure and movement of the Tasman Sea and Pacific Ocean adjacent to New Zealand and will be in charge of the IGY cruise of *Tui* in the South Pacific.

A.E. Gilmour has developed a gravimetric method of determining salinity and is at present studying tidal movements.

T.M. Skerman has made an intensive study of biological marine fouling, and is at present establishing a laboratory for microbiological investigations. In this connection, a brief expedition to Milford Sound was held at the beginning of 1957 to study the microbiology of bottom sediments. Several scientists who were visiting New Zealand for the Dunedin A.N.Z.A.A.S. 1957 meeting took part in this investigation, including Dr. Claude E. ZoBell of Scripps Institution, California, and Messrs. E. J. Fergusson Wood, I.R. Kaplan, and B.V.D. Skerman of Cronulla, N.S.W. The results are to be published in symposium form.

R.M. Cassie is developing an apparatus for simultaneous sampling of plankton and recording of temperature, salinity, and other physical variables. It is hoped that this will become a useful tool for the detailed study of local plankton ecology. Some advance has also been made in the use of free diving apparatus as a research tool.

Dr. D.E. Hurley is specializing in the study of benthic fauna and has recently completed a survey

of the Hawke Bay area partly with the assistance of the Marine Department's vessel *Ikatere*. E.W. Dawson, who is at present doing postgraduate research at Cambridge University, will also be engaged in a similar class of investigation. Dr. Vivienne Cassie has recently commenced a survey of the seasonal succession of planktonic algae in Cook Strait and Hauraki Gulf.

Lieut. Commander B.M. Bary, who has been attached to the Institute for three years, has recently accepted a post at the Oceanographic Laboratory, Edinburgh. He has developed a prototype high-speed plankton sampler which can be used both vertically and horizontally.

Dr. H.M. Pantin is carrying out geological studies of sediments and has commenced a particular investigation of the Hawke Bay region in collaboration with Dr. Hurley. Unfortunately a mishap to *Tui* during 1957 has delayed the completion of this work. The mapping of the general topography of the sea floor around New Zealand and its interpretation in relation to the geological structure of the adjacent land is being undertaken by J.W. Brodie.

Although no special provision has been made for IGY, certain investigations are being carried out as part of the global programme, including sea level and density determination, long period wave measurements, and deep oceanic currents. In this connection, one major cruise is being undertaken in the Pacific Ocean to the north of New Zealand.

Special work in collaboration with T.A. Rafter of the Dominion Physical Laboratory involves the taking of large samples of oceanic water at various depths for C^{14} dating. Results are of interest in connection with the fallout from nuclear explosions as well as shedding an entirely new light on previous conceptions on the rate of mass transport and turnover in the oceans.

The Fisheries Branch of the Marine Department maintains a small biological staff based in Wellington and a research vessel *Ikatere* which operates from Auckland but has been employed as far afield as Dunedin on investigations of commercial fisheries. Long-term research has been concentrated in the North Island, where ecological studies of the snapper and toheroa have been made by R.M. Cassie (up to 1954) and Miss M. K. McKenzie. A staff of three biologists based on Auckland, Wellington and Dunedin is concerned with ad hoc problems of more direct administrative concern.

While the University Colleges and Museums have not as yet reached the stage of having separate oceanographic departments, individual workers and groups have added to our knowledge, particularly of the biological side of oceanography. In Auckland, Dr. A.W.B. Powell's work on systematics and ecology of mollusca is being continued. Prof. V.J. Chapman has an enthusiastic group of students and postgraduate workers on marine algae and intertidal ecology.

In Wellington, the Victoria University College, Zoology Department, under Prof. L.R. Richardson, has for some time maintained a strong marine base. A research team on various vessels is engaged in investigating the deep-water fauna of Cook Strait. W.H. Dawbin has (up to 1956) amassed a considerable amount of data on the ecology and migrations of whales. Dr. R. K. Dell and J. Moreland are engaged in systematics and ecology of mollusca and fish, respectively.

At Canterbury University College, G.A. Knox has specialized in the systematics of the Polychaetes and general intertidal ecology. He was also leader of the 1954 expedition to Chatham Islands on the M.V. *Alert*. Dredge and hydrological stations were worked on the Chatham Rise by a team of workers from University Colleges, Museums and Government Departments.

At Otago University, Miss B. I. Brewin has continued her work in marine biology, particularly the systematics of the Ascidians. The Portobello Marine Biological Station, established in 1951 under Dr. Elizabeth Batham, has provided residential facilities for many marine workers. Dr. Batham specializes in the physiology of marine invertebrates.

REPORT ON PERUVIAN OCEANOGRAPHY

ERWIN SCHWEIGGER

Lima, Peru.

The Peruvian collaboration in oceanographic activities since 1952 is as follows:

1952: *BAP Bondy*[1] taking part in the Scripps' expedition "Shellback."

1953: The Peruvian Navy was represented during the explorations of the Yasa-Expedition organized by the Bingham University, Oceanographic Institute.

1954: The Peruvian Navy also helped the Billfish Expedition organized by Lou Marron with assistance of the Miami Marine Biological Institute.

1955: During the EASTROPIC Expedition of Scripps there were collaborating: *BAP Bondy* and *Pacific Queen*.[2]

I myself made investigations in 1953, consisting of various zigzag courses along the whole coast of Peru to the Gulf of Guayaquil. In 1956, I made two trips across the Peruvian Current, one in January starting from Callao Harbour and the other one in March of the same year starting from the port of Ilo (17.5° S. more or less). On cruises, I made only bathythermographic measurements of temperature-distribution, without determinations of salinity.

1 *BAP Bondy* means the Bondy, a unit of the Peruvian Navy.
2 *Pacific Queen* is a purse-seiner worked by the Guano Company under my direction.

OCEANOGRAPHIC WORK IN THE PHILIPPINES

TEODORO G. MEGIA

Head, Fish Capture Department, U.P., Philippine Institute of Fisheries Technology, Manila, Philippines.

Oceanographic work in the Philippines may be considered as a continuation on a small scale of the work started by the Philippine Fisheries Program in 1947. This program, a joint effort of the United States Fish and Wildlife Service and the Philippine Bureau of Fisheries, lasted about two and a half years. It was a well-planned venture to help rehabilitate the Philippine fishing industry which had suffered a serious setback during the last war.

The most important sea research accomplished in the Philippines during the period under review was the oceanographic survey of Lingayen Gulf done monthly from August, 1953 to July, 1954 by the M/V *David Starr Jordan*, research vessel of the Bureau of Fisheries. Water samples taken from different standard depths were collected for analysis of chlorinity, dissolved oxygen, phosphates, and pH. Temperature was measured by regular deep-sea reversing thermometers. To get an idea of the effects of tides, a 24-hour cycle observation was done every month at San Fernando, La Union, in the island of Luzon.

After the Lingayen Gulf work, the survey program was temporarily discontinued for repair of the research vessel. The vessel resumed operation only in November, 1956, when a biological survey of Manila Bay was started. This program emphasizes sampling of fish eggs, larvae, and plankton from five stations in the area and two outside Manila Bay. Simultaneous collection of water samples was made from surface and bottom for temperature, salinity, dissolved oxygen, phosphates, and pH. This work is still underway.

In intervals between Manila Bay trips, the *Jordan* went otter trawling in the northern waters of the Visayan Sea. However, the principal work done in this area was tuna long-line exploration complemented by collection and analysis of water samples.

On the basis of the foregoing, one notes that sea research in the Philippines is directed mainly to fisheries. This is highly justifiable because of the importance of fishery products to the national economy. The Philippines is a maritime country, and fish together with rice form the main food of a great segment of the population. From the standpoint of education too, oceanography plays an important role in the training of fishery students, notably those of the Philippine Institute of Fisheries Technology, now a part of the University of the Philippines.

REPORT OF THE FISHERIES DIVISION, SINGAPORE

THAM AH KOW

Fisheries Division, Ministry of Commerce and Industry, Singapore.

Since 1952 the following papers referring to activities in oceanography have been published:

Tham, Ah Kow, 1953, A Preliminary Study of the Physical, Chemical and Biological Characteristics of Singapore Straits, *Colonial Office Fishery Publication*, **1**(4). London: H.M.S.O. (This was the basis for the author's Ph.D. thesis at London University.)

Robinson, R.A., Tong, H. and Tham, Ah Kow, 1952, A Study of Drift in Malacca and Singapore Straits from Salinity Determinations, *Proceedings of the Indo-Pacific Fisheries Council.*

TUNA COMMISSION ACTIVITIES IN PACIFIC OCEANOGRAPHY

WILLIAM F. ROYCE

U.S. Fish and Wildlife Service, Juneau, Alaska.

The Inter-American Tropical Tuna Commission (IATTC) is a treaty organization joining the Republics of Costa Rica and Panama with the United States in a program of tuna research. The program in part includes investigations of physical, chemical, and biological oceanography, the object of which is to learn and understand the distributions of the tunas and variations of these distributions. Central headquarters of IATTC is at the University of California (Scripps Institution of Oceanography). The Commission does not maintain its own ocean-going vessels, but utilizes vessels of the Scripps Institution through a cooperative arrangement.

Two large-scale general surveys of the eastern tropical Pacific have been carried out: the Scripps' SHELLBACK Expedition, during the spring of 1952 and the joint SIO-IATTC participation in EASTROPIC Expedition in the fall of 1955. The Shellback data have been completely analyzed and the general distribution of properties described in a report now in press.

The Eastropic Expedition data are presently being analyzed. It is considered that with these two expeditions, the general survey of the eastern tropical Pacific is completed. Observational efforts, henceforth, will be designed to study special features believed to be important to biological production in the ocean, and to gain time series data for relating to fluctuations in tuna abundance.

Studies of special features actually began during the Eastropic Expedition when two Scripps vessels cooperatively studied the horizontal and vertical structure of the Equatorial Countercurrent employing hydrographic casts, parachute drogues, the *GEK*, the *BT*, measurements of chlorophyll-A at several depths, oblique zooplankton hauls, and productivity both in situ and in the ship laboratory incubator using the Carbon-14 uptake method. Detailed observations were also made in the region of the thermal anticline (shallow thermocline) off Costa Rica, of subsurface currents at three points along the Equator, and along the northern Boundary of the Peru Current between Ecuador and Galapagos.

In addition, the Island Current Survey during May-June, 1957 to Clarion Island was an intensive observational program employing one vessel for a month, intended to discover the influence of an island on the physics, chemistry, and biology of the adjacent ocean waters. The SCOPE Expedition (1956) in cooperation with Scripps Institution and the U.S. Fish and Wildlife Service, centered around measurements of productivity by Carbon-14 uptake along a track from San Diego to Panama. Additional biological measurements included those of chlorophyll-A, zooplankton, and bacterial abundance in the upper 200 meters, and observations of birds and mammals. Supporting physical data included measurements of submarine daylight and incident radiation, hydrographic casts, current by *GEK*, and *BT*'s.

Additional "special feature" expeditions are planned to study such things as upwelling in the Gulf of Tehuantepec and the importance of fronts in concentrating small organisms.

Time series data will be obtained from the eastern tropical Pacific using sea level recorders. We are also considering the use of recording and telemetering buoys and a new long-time temperature recorder. Temperature records are being obtained from vessels of the tuna fleet on which sea surface thermographs have been installed. *BT*'s will be taken from tuna boats during some cruises.

The Commission maintains two launches, one at Costa Rica, and one in Panama. Trips are made by these vessels in the Gulf of Nicoya and the Gulf of Panama to collect physical and biological data routinely.

The Commission has contracted the University of California to study certain aspects of the meteorology of the eastern tropical Pacific deemed significant to the oceanography. This work, being performed by the Department of Meteorology at Los Angeles, presently centers on the El Nino problem, with the object of gaining further understanding of its causes.

Of course a very large part of the Commission program involves the study of the tuna more directly, based largely on catch records from vessels of the tuna fleet, examination of tunas landed from commercial fishing vessels, and observations at sea from such vessels. We are presently engaged in a major tuna tagging effort and in studies involving not only the biology, ecology, and life history of the tunas, but also of the bait fishes which inhabit the coastal waters. It is not deemed appropriate to discuss these aspects of the program in detail in this report.

Reports of results appear in the *Bulletin of the Inter-American Tropical Tuna Commission*, which is published at irregular intervals at La Jolla, in the annual reports, and in oceanographic journals.

REPORT OF THE CALIFORNIA ACADEMY OF SCIENCES, 1951 - 1957

ROBERT C. MILLER

California Academy of Sciences, San Francisco, California, U.S.A.

The following studies have either been completed in the last four years or are now in progress:

Sex reversal in the ocean prawn *Pandalus jordani* (Peter Rubtsoff); interrelation of fishes and the invertebrate fauna in San Francisco Bay (Earl S. Herald and Kenneth T. Innes); elasmobranch fish population trends in San Francisco and Monterey Bays (Earl S. Herald and associates); bioassay of the effect of various pollutants on marine organisms (Robert P. Dempster); the role of *Crago fraciscorum* in the bio-economy of San Francisco Bay (Earl S. Herald and Kenneth T. Innes); some aspects of the physiology of Elasmobranchs (Robert P. Dempster); behavior of sardines, anchovies, and herring in an electrical field (Anatole S. Loukashkin and Tom Groody); color preference of the California sardine (Anatole S. Loukashkin and Norman Grant); temperature preference of the California sardine, northern anchovy, Pacific herring and topsmelt (Morris Morgan); factors affecting the distribution of California fishes (W.I. Follett); Pleistocene temperature conditions as indicated by the fossil invertebrates in the Gulf of California region (Leo G. Hertlein); distribution of mollusks in western tropical America (Leo G. Hertlein and W.K. Emerson); marine mollusks of Middleton Island, G.D. Hanna and Leo G. Hertlein); occurrence and distribution of Recent and Pleistocene mollusks on the Arctic coast of Alaska (G.D. Hanna); distribution of marine wood-borers in relation to ecological factors (R.C. Miller).

We have not been doing any work at sea as our navy at present consists of one 26-foot motor launch and two skiffs. We have been carrying on certain fringe activities (above) which probably come under the general heading of biological oceanography.

REPORT OF THE ALLAN HANCOCK FOUNDATION, UNIVERSITY OF SOUTHERN CALIFORNIA

K. O. EMERY

University of California, Los Angeles, California, U.S.A.

Work on problems of the ocean has been considerably expanded at the Allan Hancock Foundation during the period since 1953. Most of it is based on collections and data obtained in the region immediately off southern California. Good use is made of the R/V *Velero IV*, a 110-foot oceanographic research ship built in 1948 on a tuna clipper type of hull. An annual average of about 150 days at sea is divided among the three groups actively working on marine studies: inshore surveys, taxonomy and ecology, and general marine geology.

Inshore surveys, representing the maximum effort, began as a study of the water and sediments of San Pedro Bay for the U.S. Navy in 1954. This work led to a $250,000 industrial contract in 1955-56 to learn whether or not increased amounts of sewage from the city of Los Angeles could be discharged into the adjoining Santa Monica Bay without exceeding state standards for pollution on beaches. Also required was a recommendation for the best site for a proposed large sewage outfall. Studies were made of benthonic animals and plankton in order to evaluate the effects of past discharges and to furnish background data for comparison with future conditions; of bacteria in order to estimate decrease in populations due to dilution, settling, and mortality; of currents to learn how rapidly bacteria-containing waters would reach shore; and of bottom geology to determine the conditions to be encountered during the laying of pipe lines. So far as we know, this was the first major study of oceanographic factors that has been made prior to the beginning of any large marine engineering project. Many problems of a fundamental nature had to be set aside as too large to be solved with the available time and money or as being not of immediate urgency. Need for eventual solution of these important general problems and for comparing unpolluted and polluted regions was recognized by the state of California which provided funds for a continuation of the work as a four or five year project, encompassing the entire length of the continental shelf in southern California. Field work now occupies about half the available ship time, and field and laboratory work requires a staff of about ten full-time scientists.

The original purpose of the Foundation was to provide facilities and collections for taxonomic studies. This work has continued particularly for foraminifers, annalids, arthropods, algae, mollusks, echinoderms, bryozoans, and vertebrates. Much of it has been in the form of summaries of groups or families of organisms already present in the collections of the Foundation; some has been based on material sent from other parts of the world; and some is for new materials collected off southern California largely by the inshore surveys and the geological and biological cruises of R/V *Velero IV*.

Since much supplementary data on water and substrate are now available, some of the biological studies have taken a strong ecological trend. Work with foraminifers is largely directed toward learning their relationship to depth, temperature, and other factors in order to make better use of them as geological indicators in petroleum exploration. The annalids and some associated organisms proved to be excellent indicators of degree of sewage pollution on the continental shelf and of oxygen content of the bottom and/or interstitial waters of the fourteen deep offshore basins. Additional ecological studies were made of meso- and bathypelagic arthropods and coelenterates and their distribution as a possible function of temperature and food supply, and of plankton and attached algae as pollution indicators. The staff for the biological work consisted of four full-time members and about fifteen part-time, mostly students working on advanced degrees.

Work in marine geology and oceanography of the offshore basins has been directed mostly toward gaining an understanding of these basins with respect to their now-filled counterparts on land which are the sites of rich oil fields. Oceanography during this period included a study of the source and fate of basin waters, their movements within the basins, and their chemical gains and losses to the bottom sediments. The contents of total organic matter, hydrocarbons, and green porphyrin pigments in the sediments were found

to be more than adequate for the amount of petroleum likely to be formed, judging from production and reserves of the filled basins now on land. In addition, petroleum gases were discovered and measured in the bottom sediments of the basins. Fundamental to most geochemical work is the time scale; this is being investigated through radiocarbon measurements of cores in order to establish rates of deposition in the various basins. Studies of offshore lithology, stratigraphy, and structure have continued by dredging operations. Finally, detailed sounding profiles across the mainland and island shelves and bank tops have shown the presence of five shallow terraces that together comprise the continental shelf and which reveal a regional warp of the entire offshore region that has continued from Miocene times to the present. The staff for this work consisted of two members plus about ten students working on advanced degrees at various times.

Although the Foundation is a research rather than a teaching institution, qualified graduate students are encouraged to study Foundation collections and data and to participate in shipboard work. Course work for graduate students is in the department most closely concerned, but the research is directed by a member of the Foundation staff who usually is also associated with a teaching department. Since 1953, fifteen masters and seven doctorates have been based on work done at the Foundation by students of the geology and biology departments. In addition, facilities were provided for advanced research by scientists of other marine research institutions of the United States and of several foreign countries. Since 1953, a total of 140 papers have been published by members of the Foundation or by others working on its collections, and 40 more are in press or in preparation. This large fund of knowledge about a particular region of the sea will lead during the next few years, it is hoped, to a more complete integration of the interrelationships between plants, animals, water, and sediments than has been possible for many other areas of similar size and complexity.

Fig. 1.—R/V *Velero IV*, Marine Laboratory of the University of Southern California.

RESEARCH BEING DONE BY THE CALIFORNIA COOPERATIVE OCEANIC FISHERIES INVESTIGATIONS ON OCEANOGRAPHIC ACTIVITIES IN THE PACIFIC

ELBERT H. AHLSTROM

South Pacific Fisheries Investigations, Scripps Institution of Oceanography, La Jolla, California, U.S.A.

The California Cooperative Oceanic Fisheries Investigations are being carried out cooperatively by the following five organizations: California Academy of Sciences, Hopkins Marine Station of Stanford University, the California Department of Fish and Game, Scripps Institution of Oceanography of the University of California, and the South Pacific Fishery Investigations of the U.S. Fish and Wildlife Service. The research is coordinated by the California Marine Research Committee. Four of the organizations are doing oceanographic-biological research; the effort of Hopkins Marine Station is mostly confined to Monterey Bay; that of the California Department of Fish and Game is mostly incidental to surveys designed to assess abundance of juvenile and adult fish, but Scripps and the Fish and Wildlife Service are carrying out a coordinated survey program that is perhaps the largest of its kind.

The area that has been systematically surveyed is a strip of ocean off California and Baja California that extends approximately 1,400 miles from north to south and 200 to 250 miles seaward. The whole area is not covered on every cruise. The area between Point Conception, California, and Point San Juanico, Baja California (700 miles from north to south) is occupied on almost every cruise; coverage to the north of this (central and northern California) is usually made during the spring and summer months; and coverage to the south (southern Baja California) is usually made during the winter months and sporadically at other seasons.

During the past two years, seven cruises have been made into the Gulf of California; usually the coverage has extended from the head of the Gulf to below the mouth of the Gulf.

The most comprehensive coverage of the eastern north Pacific was obtained on Norpac during 1955 (July-September). The area between 20°-45° N. latitude and offshore to 150° W. longitude was covered by agencies participating in the California Cooperative Oceanic Fisheries Investigations. Four vessels were employed in obtaining the hydrographic and biological data, three operated by the Scripps Institution of Oceanography, the other by the South Pacific Fishery Investigations. Other agencies (Japanese, Canadian, and American) took part in this comprehensive survey of the Pacific Ocean to the north of 20° N. latitude.

Descriptive oceanography of the California Cooperative Oceanic Fisheries Investigations is being carried out by the Scripps Institution of Oceanography. Scripps operates a fleet of six research vessels, one to three (usually two) of which are employed on most monthly cruises.

Hydrographic cruises now are limited to four per year, one in each season; on these cruises temperature, salinity, and oxygen are measured to a depth of 600 meters on about one hundred stations. On monthly survey cruises other than hydrographic cruises (usually called egg and larval survey cruises) temperature measurements (*BT*, thermograph, 10 and 50 meter reversing thermometers), current measurements *(GEK)* and certain limited salinity samples are taken. Usually between 100 and 225 stations are occupied per cruise.

Among the projects underway is the preparation of an Atlas of the North Pacific Ocean, being prepared in conjunction with the other agencies (Japanese, Canadian, and American) who participated in the Norpac cruise of 1955. It is the data from that cruise which are being used in the Atlas. The Descriptive Oceanography Group, as well as preparing part of the charts, is comparing the others and making a final homogeneous interpretation of the various fields which have been prepared by Scripps and the other agencies.

The status of knowledge to the California current has been summarized in the *Annual Progress Report* 1956-57 of the California Cooperative Oceanic Fisheries Investigations (in press), and work on understanding the relation of the physical oceanography to the organisms is continuing.

In the study of these relations, long series of

temperature measurements are being examined, and the effect upon them of long-term wind variations is being studied.

The nature of short-period fluctuations of surface currents and the vertical oscillations of the thermocline (internal waves) are being studied, as they seriously affect the measurement of the California current. The deeper north-flowing water is being examined and a theoretical explanation sought for the northerly flow at depth.

The South Pacific Fishery Investigations participates in collections of hydrographic and biological data at sea, operating a research vessel, the *Black Douglas*. They are interested in population dynamics of pelagic fishes, particularly the Pacific sardine.

A primary objective of this survey program is the determination of the distribution, abundance, and mortality of sardine eggs and larvae. The egg data are used in conjunction with fecundity estimates to obtain estimates of the size of the sardine spawning population and its areal distribution during spawning season. The South Pacific Fishery Investigations are investigating the causes behind the success or failure of year-classes of sardines. During the past 20-year period, the largest year-class of sardines (1939) furnished over 50 times as much fish to the commercial catch as the smallest year-class (1949). They are testing a widely held assumption that the early postembryonic (larval) period is the most critical in the life of a pelagic fish as regards mortality. Infant mortality is high and it is variable: the success or failure of year-classes of sardines and other fishes is assumed to be determined during this period. During the period of the expanded investigations, there have been a succession of below-average year-classes and no successful ones. It is interesting to note, however, that the most successful year-class of the group, albeit, still a middling one, (1952-class) showed the highest rate of survival as larvae.

The distribution and abundance of the eggs and larvae of other pelagic fishes are also being investigated—particularly the young stages of the northern anchovy, jack mackerel, Pacific mackerel, hake and rockfish. During the period of expanded investigations (1949 to date), there has been a marked increase in the anchovy population off southern California and Baja California. This species has had a number of successful year-classes, particularly the 1952-, 1953-, and 1954-classes.

Other problems being investigated at sea by the South Pacific Fishery Investigations include the factors influencing availability of fish (sardines) to the fishermen, and the determination of the number of subpopulations of sardines.

Zooplankton volumes for all hauls made on survey cruises and the basic data on fish eggs and larvae are published in reports that appear annually. Several reports have been published on the distribution and abundance of egg and larval populations of pelagic fishes (sardine, jack mackerel, hake), and others are in press or preparation.

The constituents of the plankton, other than fish eggs and larvae, are being investigated by the Scripps Institution of Oceanography. Among the research projects being conducted are studies on food of larval fishes, particularly the sardine, anchovy, and jack mackerel and the relation between distribution of the larvae and their basic food constituents; studies on indicator organisms that can be used to characterize water masses, and studies on taxonomy, distribution and abundance of a number of zooplankton groups including thaliacea, euphausiids, amphipods, copepods, chaetognaths, Panilurus, and planktonic mollusca. Studies are also being conducted on phytoplankton.

REPORT ON OCEANOGRAPHIC ACTIVITIES OF THE MARINE FISHERIES BRANCH OF THE DEPARTMENT OF FISH AND GAME OF THE STATE OF CALIFORNIA

LEO PINKAS

California State Fisheries Laboratory, San Pedro, California, U.S.A.

The oceanographic activities of the Department range from full scale hydrographic cruises to limited observations for supplementary data for the primary objectives. Full-scale operations have been few in number and all in connection with the California Cooperative Fishery Investigations. Observations and methods used were those outlined by Scripps Institution of Oceanography, La Jolla, California, which received and processed all data.

In general the following types of observations are made on all hydrographic cruises: bathythermograph cast with accompanying data; surface water temperatures at various depths, water temperatures and water samples which are analyzed for oxygen, phosphates and salinity and plankton tows, oblique 140 meters to the surface.

Limited observations are the norm on our cruises; they usually include bathythermograph casts at regular intervals in space and time and surface water temperatures. Other observations are taken sporadically depending upon the objectives of the cruise. They include Seccii disc readings, vertical plankton tows, and water samples and temperatures at depths.

REPORT OF OCEANOGRAPHIC ACTIVITIES OF THE HOPKINS MARINE STATION, 1953 - 1957

ROLF L. BOLIN

Stanford University, Hopkins Marine Station, Pacific Grove, California, U.S.A.

With financial support from the Office of Naval Research and the National Science Foundation, the Hopkins Marine Station has pursued an investigation of the correlation between variations in hydrographic factors and fluctuations in the populations of plankton organisms. Due to the small size of the research vessel *Tage* (12½ m.), the field work was limited to a small local area off the central California coast. At weekly intervals for a period of five years, plankton samples and water samples were taken at various depths to 1,000 m. Selected species were sorted and counted; and the temperature, salinity, oxygen, phosphate, and silicate determined. These data are now being analysed for reports.

A by-product of the major problem was the investigation of annual changes in the character of the deep scattering layer, and the determination of the organisms responsible for scattering patterns of various types. A report on this phase has appeared as Technical Report No. 1 under the title: *The Ecology of Sonic Scattering Layers in the Monterey Bay Area*, by E.G. Barham, Feb. 11, 1957, 182 pp., 31 figs.

Additional work, as part of the California Cooperative Oceanic Fisheries Investigation, is in progress and involves a weekly check on the magnitude of local upwelling through determination of the temperature and salinity at six stations extending in a line across the mouth of Monterey Bay. Phytoplankton and zooplankton volumes from standardized net hauls taken at each station are recorded as a rough measure of productivity, and the dominant species in the catches are recorded. These biological data supplement the physical data and permit what is believed to be a good estimate of the general direction of flow of the upwelled water and the relative permanence of local eddies at the northern and southern extremities of the bay.

REPORT OF THE SCRIPPS INSTITUTION OF OCEANOGRAPHY, 1953-57

MARTIN W. JOHNSON

Scripps Institution of Oceanography, University of California, La Jolla, California, U.S.A.

The La Jolla campus of the University of California was until 1953 known only as the home of the Scripps Institution of Oceanography. In 1953, the Regents of the University established on the La Jolla campus the headquarters of a statewide University activity, the Institute of Marine Resources, whose objective is to utilize our knowledge of the sea for the benefit of mankind.

In the next decade or so the La Jolla campus is destined to fulfill an even larger purpose, for in 1956 the Regents directed that the Scripps faculty and facilities be expanded to provide a program of instruction and research in all aspects of science and technology. The Scripps Institution, as an integral part of the new campus, will continue its traditional research and teaching in the sciences of the sea.

During the past year, the previously existing academic divisions of the Scripps Institution have been consolidated into four groups. The new divisions are those of Marine Biology, Marine Geology and Geochemistry, Marine Geophysics, and Marine Resources. This simplification and consolidation of the academic organization was considered desirable both from the standpoint of administration and for the program of graduate instruction and research.

The past five years have seen the establishment on the La Jolla campus of two research laboratories whose work is integrated with that of the Scripps Institution. These are the Inter-American Tropical Tuna Commission and the South Pacific Fishery Investigations of the U.S. Fish and Wildlife Service.

Supporting activities of the Institution include the Library, Thomas Wayland Vaughan Aquarium-Museum, Marine Facilities, Service Shops, Publications, and other service organizations.

Roger Revelle, Professor of Oceanography, has served as Director of the Institution and as Chief Local Administrator of the La Jolla campus since 1951. Charles D. Wheelock, Rear Admiral, USN (ret'd), who had served as Acting Director of the Institute of Marine Resources since its foundation, was named Director in 1957.

The total staff of the Institution has risen to a total of more than 600 persons. Approximately 120 of these have academic appointments.

The annual budget of the Institution now stands at approximately three million dollars. About one-third comes from the State of California; endowments, foundations, industry, and the federal government supply the rest. The federal government, and particularly the U.S. Navy, contributes by far the largest share.

Recently the Institution has received two notably generous grants, each for one million dollars. The first was given by the Rockefeller Foundation to aid research in marine biology. This has been used to support new staff members and several postdoctoral fellows. It has also provided assistance to the permanent staff. The second million-dollar gift came from General Dynamics Corp. and is to be used in support of the expanded campus.

The major physical growth over the 1953-57 period came with the construction of a new research laboratory building of 21,240 square feet, which was completed in 1955. Plans are being drawn for an experimental aquarium and for two new research laboratory buildings similar in size to the one completed in 1955.

The Institution now operates six vessels in its research fleet. They are *Horizon*, 143 feet; *Spencer F. Baird*, 143 feet; *Stranger*, 134 feet; *Orca*, 100 feet; *Paolina-T*, 80 feet; and *T-441*, 65 feet; as well as smaller craft. The larger vessels are capable of traveling to any part of the Pacific.

Far-ranging are the expeditions conducted by the Institution. During the past five years, twelve of these have been carried out, in addition to shorter, routine cruises along the California and Baja California coasts.

The expeditions are:

TRANS-PACIFIC, to the Aleutians and Japan, in 1953.

TORO, to Central America, in 1954.

ACAPULCO TRENCH, to Central America, in 1954.

NORPAC, across the entire breadth of the North Pacific, in 1955 (in cooperation with the

Pacific Oceanic Fishery Investigations; the Pacific Oceanographic Group, Canada; the University of Washington: the Japanese Hydrographic Office; Tokyo University; the University of Kokkaido; Hakodate Marine Observatory; and the Tokyo University of Fisheries).

EASTROPIC, to Peru, in 1955 (in cooperation with the Inter-American Tropical Tuna Commission).

CHUBASCO SEGUNDO, off Central America, in 1956.

CHINOOK EXPEDITION, to the Gulf of Alaska, in 1956.

EQUAPAC, to the equatorial Pacific, in 1956 (in cooperation with the Pacific Oceanic Fishery Investigations, the Institut Français d'Océanie, New Caledonia, and several Japanese research agencies).

SCOPE, to Panama, in 1956.

ISLAND CURRENT SURVEY, to the Revillagigedo Islands off Mexico, in 1957 (in cooperation with the Inter-American Tropical Tuna Commission).

SIGRE, to the Revillagigedo Islands in 1957 (in cooperation with the Institute of Geophysics, University of Mexico).

MUKLUK, to the Aleutian Islands, and the Bering Sea, in 1957.

During the past five years, the Institution has been honored by the election of six members of its research staff to the National Academy of Sciences. These are Milton N. Bramlette, Carl Eckart, Walter M. Elsasser, Carl L. Hubbs, Walter H. Munk, and Roger Revelle.

The scientific program of the Institution is broad and diverse. It will be described by dealing in turn with each of the four major divisions, but one should recognize that such a description is strictly formal: there is constant cooperation between the various disciplines as they study the complex and indivisible sea.

MARINE BIOLOGY

The Division of Marine Biology is headed by Claude E. ZoBell. Some members of the biology staff are Martin W. Johnson, Carl L. Hubbs, Denis L. Fox, and Francis T. Haxo. The following studies have been conducted:

Microbiology

Marine microbiologists have been concerned primarily with the occurrence, characteristics, and physiological activities of bacteria in the deep sea. Apparatus and techniques have been developed for investigating the effects of high hydrostatic pressures on the morphology, reproduction, respiration, enzyme reaction rates of bacteria. Studies have been continued on accessory growth factors, micronutrient, and physiochemical cultural requirements of marine bacteria, including the effects of solid surfaces. Long-range experiments are in progress on the microbial deterioration and/or corrosion on iron, steel, plastics, wood, and other man-made structures in the sea. The decomposition of chitin and hydrocarbons has received special attention.

Botany

The research activities of this group have been largely directed towards gaining a better understanding of the physiology and ecology of the marine algae, both planktonic and attached. Problems of primary interest have been photosynthesis in variously colored algae, bioluminescence of dinoflagellates, and the productivity, abundance, and distribution of phytoplankton in the eastern Pacific Ocean.

Genetics

Problems of speciation, population genetics, and genetic systems in marine animals have been examined by cytogenetic techniques, selection experiments, and population analysis. Examination of genetic systems, chromosome cytology, mating types, growth factor requirements and bacteria-free growth of algal cultures have been carried out on both unicellular and multicellular algae. In a study of the (bio)chemical ecology of the ocean, microbial genetic techniques have permitted isolation of auxotrophic mutants of a marine bacterium which serve as bioassay organisms.

Biochemistry

The chemistry, comparative metabolism, and disposition of natural pigments in marine animals (e.g., birds, fishes, and certain invertebrates) and in biochemical fossils in the muds of the sea floors have been studied. Research has been conducted on organic detritus, particulate and soluble, in the metabolism of the sea, in sediments, and in marine surface slicks. Studies have been conducted of the role of organic matter and marine bacteria in the corrosion of immersed metallic surfaces. Other studies have included those on elasmobranch liver-enzymes, their comparative action upon intermediary nitrogenous substrates; on bioluminescent responses

to electrical stimuli applied to fishes and invertebrates; on the sources, chemical nature, and physiological action of various marine animal venoms; and on pigmentation and threshold responses to photic stimuli in anemones.

Invertebrates

Studies of marine invertebrates have been concerned largely with the analysis of plankton collected on the various expeditions in the Pacific Ocean, the Chukchi and Beaufort Seas, and on the routine Marine Life Research cruises along the California coast. The analysis has involved especially geographic, taxonomic, ecologic, and life history considerations of euphausiids, chaetognaths, pelagic tunicates, copepods, and the California spiny lobster. A program of studies using self-contained breathing apparatus (SCUBA) has been initiated to investigate the ecology and habits of benthic invertebrates in subtidal areas. The neuromuscular physiology of certain sessile coelenterates is being studied.

Vertebrates

Studies have actively continued on the oceanic and littoral fishes, birds and mammals, involving life histories, distribution, systematics and speciation (especially of fishes and marine birds on the isolated Guadalupe Island, Mexico). The Guadalupe fur seal has been rediscovered, and the increase of this and other species of marine mammals followed. The analysis of the California fish fauna has been actively continued. Serological analyses have been made of certain fishes and an extensive investigation of the lateral line of fishes is under way.

MARINE GEOLOGY AND GEOCHEMISTRY

Fred B. Phleger is Chairman of the Division of Marine Geology and Geochemistry. His associates include Milton N. Bramlette, Francis P. Shepard, Douglas L. Inman, Tj. H. Van Andel, Henry W. Menard, Jr., in geology; and Norris W. Rakestraw, Gustaf O. Arrhenius, Edward D. Goldberg, Hans Suess and Harmon Craig, in chemistry.

Geology

Geological investigations have included:

1. A study which is nearing completion of several thousand sediment samples from the bays, deltas, barrier islands and continental shelf along the coasts of Texas and Louisiana. Criteria have been developed for distinguishing the various environments. For this purpose, in addition to the faunal assemblages and grain size parameters, the general composition of the coarse fraction constituents and the sedimentary structures have proven especially valuable. Approximate rates of deposition during the last few thousand years have been determined for some of the sediments.

2. Effort has also been concentrated on the following subjects: Trenches. The topography of the Aleutian, Kurile, Japan, Tonga, Middle American and South America trenches have been explored. Fracture Zones. The existence of the fracture zones of the northeastern Pacific has been confirmed and several sections have been surveyed in some detail. Seamounts. Scores of seamounts have been discovered; some idea has been gained of their total number (5,000-10,000) and distribution in provinces. Archipelagic Aprons. The smooth plains surrounding all explored island groups in the western Pacific were discovered and explored during this period.

3. Members of the Foraminifera Laboratory have studied the ecology of modern Foraminifera and applied the results to the study of sedimentation, eustatic shifts in sea level, turbidity current processes, distribution of marine water masses, and chronologies recorded in deep-sea cores.

4. Studies continue on the distribution of coccolithophorids, discoasters, and certain mineral assemblages in deep-sea cores and the distribution and sequence of Radiolaria in deep-sea sediments.

Geochemistry

Main fields of study in biogeochemistry have been the structure and composition of minerals formed by precipitation from solution in the ocean, with the aim of elucidating the processes of formation and their changes in the past; transfer of trace elements from the ocean to the bottom deposits by sorption processes and by incorporation in the structure of authigenic minerals; stratigraphy of pelagic sediments, and the relation between the stratification and variations in the processes of formation; and concentration of trace elements by plankton and nekton.

Geochemical investigations have also included work on the isotopic composition of lead from sediments from the Pacific Ocean; studies on the thorium concentration in manganese nodules;

studies on the use of neutron-irradiated quartz as a tracer of sand movements; studies on the distribution of radioactivity in pelagic clays and in manganese nodules. Further, a number of instrumental methods have been developed: the use of X-ray spectroscopy for the determination of metals in deep-sea sediments; the polarographic determinations of ferrous and ferric iron in sediments; and the determination of opal in pelagic sediments by X-ray diffraction techniques.

Geophysics

Chairman of the Division of Marine Geophysics is Robert S. Arthur.[1] During the past year or more, this Division, particularly, has been deeply involved in the oceanographic program of the International Geophysical Year, as has been the Division of Marine Geology and Geochemistry, for it is the Scripps Institution's responsibility to coordinate the American oceanographic program of IGY in the Pacific.

The oceanographic program of IGY has been described by Roger Revelle in the following manner:[2]

> The oceanographic program for the International Geophysical Year has gradually developed into a most elaborate and far-reaching one. Nearly 75 research vessels from many different countries will each spend many months at sea. Forty-eight of these ships will be in the Atlantic, and twenty-five in the Pacific. There will be eight American and about a dozen Russian ships. The Russians plan to maintain an oceanographic ship in the Antarctic Ocean throughout most of the year. Both the USSR and the USA will carry out large-scale expeditions in the Atlantic and the Pacific, and other countries will cooperate to extend the areas covered.
>
> The oceanographic program has two principal objectives. The first is to measure the currents at great depths in the ocean. Practically nothing is known about these deep currents. This is understandable—it is not because oceanographers are incompetent, but because it is difficult and expensive to make measurements below the iron curtain of the sea's surface, and effective methods have only recently been developed. Such measurements must be made on ships—the oceanographers don't have the advantage that the meteorologists have of being able to send up inexpensive balloons from fixed land stations. So little is known about the circulation of the deep ocean water that nobody knows whether it takes a hundred years or ten thousand for this water to travel from the Antarctic to the Equator and back again.
>
> Why should we try to learn more about the deep ocean currents? It is easy to give several practical reasons—one is that the deep currents may be of great importance in long-range weather forecasting, particularly because of the exchange of water between the Antarctic and low latitudes. Second, the fertility of the ocean depends upon the water exchange between the deeps and the surface; that is, the amounts of fish and other food we can harvest from the ocean are finally limited by the rate at which the ocean overturns and thereby fertilizes itself. In order to get a better estimate than we can make at present of what the potential food supply from the ocean is, and to learn how we can do something about it, we have to know about the deep currents. Third, the development of peaceful uses of atomic energy will probably result in the production of unbelievable quantities of radioactive substances, and somehow these must be safely disposed of. One possible thing to do with them is to dump them into the deep sea; its currents might spread them out to such an extent that they would be harmless. But we really don't know whether this would be true or not because we don't know how fast the deep waters move or how they mix with the waters near the surface.
>
> The deep water circulation of the oceans will be one of the major objects of investigation of the great series of oceanographic expeditions that will be sent out during the International Geophysical Year. At the same time, considerable effort will be expended during these expeditions to find out more about the shape of the deep-sea floor and about the interior of the earth. We can't really understand such things as the distribution of mineral deposits, nor can we develop geological methods to find resources to feed the insatiable maw of our industrial machines, until we know more about the history of the earth, and we can't get much further with this history until we find out more about that part of the earth that is covered by the ocean. At present we know less about it than we do about the surface of the moon.
>
> The other principal objective of the oceanographic program will be to make a continuous record of the changes in sea level over the course of the year in all the oceans. This is called the Island Observatory program. We know that sea level changes with the seasons. In summer and autumn, it is about a foot higher on the average than in winter and spring. This change in sea level is undoubtedly due, in part at least, to the transport of water by the great ocean currents. If the water goes up here and goes down there, some water must go from here to there. Here at last we may have an inexpensive means, using observing points on land, of measuring the changing motions of the oceans. During the International Geophysical Year, sea level will be measured at some hundred newly established stations on islands, as well as at the tide gauge stations on continental shores already in existence, in order to see if it is possible to find out how the ocean moves by this cheap and interesting method of measuring the changes in the levels of the water.
>
> The Island Observatory program is an example of the kind of scientific effort in which international collaboration is essential, for no one country can find out all it needs to know about the problem involved without the close and continuous cooperation of many

[1] His Colleagues include Carl Eckart, Walter M. Elsasser, Russell W. Raitt, Leonard N. Liebermann, Alfred B. Focke (Director, Marine Physical Laboratory), Seibert Q. Duntley (Director, Visibility Laboratory) and Walter. H. Munk.

[2] Speech before Session X6-A.A.A.S., Symposium on the International Geophysical year.

countries. It represents, therefore, a sort of model of what the International Geophysical Year is all about.

Among the research projects of the Division of Marine Geophysics have been the following:

Sea Surface. Statistics have been derived of the sea surface from photographs of the sun's glitter; this has led to discussions of the albedo of a rough surface, and of the wind stress on water. Offshore and nearshore measurements of low-frequency waves (periods 25 seconds to 2 hours) have been made. The seasonal oscillation of sea level on a world-wide basis has been described.

Seismic Exploration of the Sea Floor. Seismic measurements have been made on eight cruises and another is planned for late 1957. It has been found that the continental borderland off California has a structure intermediate between typical continental and oceanic structures. The Central American Trench shows a thickening of the crust similar to that previously found beneath the Tonga Trench. Other studies have extended south to Costa Rica and north to the Bering Sea.

Electromagnetic Phenomena. The propagation of radio waves generated by lightning has been investigated in the hitherto unexplored spectral region below 500 cps.

Acoustics. An experimental study of the effect of pressure on acoustic absorption by magnesium sulfate (the principal cause of absorption in sea water) has been completed. An investigation is being made of the scattering of sound by small air bubbles in water. Studies have been made of the formation and solution of air bubbles. Their formation has long been thought to initiate at microscopic hydrophobic sites known as nuclei: microphotographs of the nuclei have been obtained for the first time, and other experimental evidence supporting this theory has been obtained.

Equation of State of Sea Water. A critical survey of existing data on the compression of water and sea water has been made. The specific volume of sea water as a function of temperature, pressure, and salinity is much less certain than has usually been supposed.

Theory. Studies have been made of the theory of surface wave generation, of the scattering of light from rough surfaces, of random oscillations in general, and of the motion of stratified fluids such as the ocean and atmosphere.

Random Motion of Floating Objects. The random motion of drogues having low wind resistance has been studied.

Visibility and Marine Physical Laboratories. Operating within the academic framework of the Division of Marine Geophysics but administratively semi-independent are two distinguished laboratories dealing with basic physical research on problems of concern to the Armed Services. These are the Visibility Laboratory, which deals with problems of visibility in the sea and in the air, and the Marine Physical Laboratory, which is concerned with such problems in marine physics as the acoustical properties of sea water.

DIVISION OF MARINE RESOURCES

While the similarly named Division of Marine Resources and Institute of Marine Resources work closely together and in the same general field of endeavor (and are headed by the same person, Charles D. Wheelock?), there are important distinctions between them. The Scripps Institution's Division of Marine Resources is primarily concerned with the collection, processing, and interpretation of physical and chemical data and with such problems in oceanography as the disposal of atomic wastes. Its research staff includes John D. Isaacs, Joseph L. Reid, Jr., Warren S. Wooster, and Margaret K. Robinson. The Institute of Marine Resources, on the other hand, utilizes such data and other information in studies directed at applications of basic oceanographic research.

The collection, processing, and interpretation of physical and chemical data falls under three principal headings.

Data from the CCOFI Program

Jointly with the California Department of Fish and Game, the U.S. Fish and Wildlife Service, the California Academy of Sciences, and Hopkins Marine Station, Stanford University, the Institution participates in the California Cooperative Oceanic Fisheries Investigations (formerly the California Cooperative Sardine Research Program). The Institution's share of this research endeavor is known as the Marine Life Program and has been supported since 1949 by the California Legislature. The investigation has placed the greatest emphasis on studying the ecology of the California sardine, including its food and life history. The study, however, involves basic research on other pelagic fishes, such as sauries, anchovies, and mackerel; on the phyto- and zooplankton; and on the chemical and physical factors operative in the environment.

With only a few omissions, monthly cruises have been conducted along the coast of California and Baja California from San Francisco southward. Lately the cruises have extended to the Gulf of California and some distance south. Three or more ocean-going vessels participate in each cruise.

The Scripps Institution's share of the biological investigations under this program have dealt with phyto- and zooplankton, which have been mentioned in the section on the Division of Marine Biology, the development of instruments, and the collection and analysis of the physical and chemical data.

Data From the Long Cruises

One aspect of research in the Division of Marine Resources is concerned with the processing and interpretation of the physical and chemical data from the long cruises of the Institution and to extending the descriptive oceanography of the Pacific.

Members of this division will make studies of the water circulation in the Pacific as part of the IGY program mentioned earlier.

Bathythermograph Data

Still another branch of the Division of Marine Resources maintains the oceanographic archives of the Institution and processes and analyses bathythermograph data from the Pacific.

These three groups have as another responsibility the preparation of the series *Oceanic Observations of the Pacific*, compilation of oceanographic data issued by the University of California Press. The first volume, containing data taken in the year 1949, has already appeared; the second and third, which will be devoted exclusively to the data taken on Norpac, are currently in preparation. They will appear as a joint publication by the University of California and the University of Tokyo.

INSTITUTE OF MARINE RESOURCES

The Institute of Marine Resources has sponsored work in the Division of Marine Geology and Geochemistry (on the recent sediments of the Texas and Louisiana coasts), in that Division and in the Division of Marine Biology on pollution, on the effects of underwater explosions on fishes, and on kelp. A study of fish life in the kelp beds has appeared. Another investigation, supported by the State of California, got under way in 1956-57, continuing and greatly expanding researches previously supported by an industrial grant. The giant kelp has been extensively cultivated in the laboratory and much has been learned of the factors favorable and unfavorable for kelp growth.

PUBLICATIONS

During the years 1953-56, a total of 317 scientific papers by Scripps staff members appeared in the scientific journals.

ACTIVITIES IN OCEANOGRAPHY AT OREGON STATE COLLEGE

WAYNE V. BURT

Associate Professor of Oceanography, Oregon State College, Corvallis, Oregon.

A program in estuarine and coastal oceanography was started at Oregon State College in the fall of 1954 under the sponsorship of the college and a contract with the Office of Naval Research. Since that time, additional support has been given by the U.S. Fish and Wildlife Service and the Fish Commission of Oregon.

Estuaries. The principal research program is concerned with the physical ecology of Oregon's numerous coastal estuaries. The most pressing problem is the study of the flushing of contaminates from existing and proposed industrial plants and other sources. The combination of supplies of fresh water, pulp-grade timber, and easy access to ocean shipping is encouraging the development of a number of wood pulp product plants on the estuaries. Mr. William B. McAlister, a physical oceanographer, has recently joined the program to continue work on the flushing problem.

Light Transmission. The second research program has to do with light transmission in natural waters, with the purpose of using optical means for the determination of suspended particle size. The author participated in the Scripps Institution of Oceanography Eastropic Expedition to the east Tropical Pacific to carry out optical studies. Further participation on deep-sea cruises is planned.

Equipment and Facilities. Headquarters for the program are on the college campus in Corvallis, Oregon—an hour and a half drive from the deep-sea port of Newport on the Yaquina Bay. A chemical laboratory and office space are on the campus. Facilities are also available at seven biological field stations and laboratories located on the estuaries which are operated by the Fish Commission of Oregon and the two state universities.

A fast, 16-foot plastic cabin cruiser has been purchased for use on the estuaries. It is equipped with the usual small oceanographic gear as well as a conductivity-temperature-indicator for rapid *in situ* determination of salinity and temperature. The speed of the boat is sufficient to follow the stages of the tides as they progress upstream.

Academic Activities. Three courses are offered in the Department of General Science: an introductory course in general oceanography, a graduate course in physical oceanography, and a graduate course in physical limnology. The latter two are primarily for fishery students. A growth in academic activities is planned for the near future.

Opportunities are available to take work toward advanced degrees in General Science with thesis work on oceanographic problems. Some progress has been made in interesting and recruiting qualified graduate students for further advanced training at departments of oceanography at other universities. Students have also participated in oceanographic cruises of the University of Washington and the U.S. Fish and Wildlife Service.

Temperature in Reservoirs. Recently, a two-year program was undertaken for the U.S. Fish and Wildlife Service to predict the thermal structure in proposed reservoirs on the Snake River.

Material in Preparation. The following papers have recently been submitted for publication: (1) Tidal Over-mixing in Estuaries; (2) A Note on the Micro-climate of the Oregon Coast; (3) Can Mid-latitude Storms be as Severe as Typhoons?; (4) Selective Transmission of Light in Tropical Pacific Waters; and (5) Flushing of Pollutants in the Yaquina River Estuary.

Publications. All, or part, of the research and writing for the following publications was done under the oceanographic program at Oregon State College.

Burt, Wayne V., 1954, Specific Scattering in Uniform Minerogenic Suspensions, *Tellus*, **8** (3): 229-231.

———, 1955a, Interpretation of Spectrophotometer Readings on Chesapeake Bay Waters, *Journal of Marine Research*, **14** (1): 33-46.

———, 1955b, Distribution of Suspended Materials in Chesapeake Bay, *Journal of Marine Research*, **14** (1): 47-62.

Burt, Wayne V., 1956 a, A Light Scattering Diagram, *Journal of Marine Research*, **15**(1): 76-80.

———, 1956 b, An Ocean in Miniature, *Research Reviews*, June, 8-10.

———, 1957, On the Attenuation of Light in the Sea, *Journal of Marine Biological Association* **36** (2): 223-226.

Danielson, E.F., Burt, Wayne V., and Rattray, Maurice, Jr., 1957, Intensity and Frequency of Severe Storms in the Gulf of Alaska, *Transactions of American Geophysical Union*, **38** (1): 44 - 49.

Rattary, Maurice, Jr. and Burt, Wayne V., 1956, A Comparison of Methods for Forecasting Wave Generation, *Deep-Sea Research*, **3**: 140-144.

REPORT OF U. S. COAST AND GEODETIC SURVEY

CHARLES PIERCE

Coast and Geodetic Survey, U.S. Department of Commerce, Washington, D.C., U.S.A.

Seven ships of the Coast and Geodetic Survey, in addition to shore-based survey parties, have been engaged in hydrographic surveys of Pacific waters. Although most of these surveys have been close ashore and inside the coastlines, offshore and deep-sea surveys are included. Enroute to and from survey areas in Western Alaska, two to four ships have run more than 40,000 miles of deep-sea sounding lines in the past five years. The number of such crossings now total 93. As a result of these exploratory surveys across the head of the Northeast Pacific, the character of the ocean floor is becoming extensively revealed. Considerable bathymetric detail of seamounts and the Aleutian Trench has been obtained in the past five years, since acceleration of this survey program in 1953. The sounding lines are now interrupted for three days on each trip for detached surveys of seamounts, which numbered 70 during this period. The results of these oceanographic activities are reflected in part in Coast and Geodetic Survey Chart 8500 and in papers published by scientific personnel of oceanographic institutions.

In the United States and Alaska, tide stations were continued in operation as follows: 19 along the Pacific coast of the United States and 10 in Alaska. In continuing the program of tidal investigation in the Pacific Islands area, tide stations are being maintained at 14 locations: 7 in the Hawaiian area, 1 at Wake, 2 in the Marshalls area, 1 in the Mariannas area, 1 in the Carolines area, 1 in the Samoan area, and 1 in the Phoenix area. In addition, records are being processed in this office from 16 stations maintained in the Pacific area of Latin America by the Inter-American Geodetic Survey.

The tide observers at most of these stations also make a daily observation of sea water temperature and density. The results are published in Special Publication No. 280, "*Surface Water Temperatures, Pacific Coast, North and South America and Pacific Ocean Islands*" and Special Publication No. 281, "*Density of Sea Water, Pacific Coast, North and South America and Pacific Ocean Islands.*"

During the course of hydrographic surveys in Alaskan waters, Coast and Geodetic Survey ships observed currents at a number of stations and made serial observations of temperature and density for use in the surveys. They also made numerous bathythermograph observations for the U.S. Navy Hydrographic Office. Extensive current surveys were conducted in San Francisco Bay and Puget Sound.

The Seismic Sea Wave Warning System was continued in operation and now includes 18 tide stations and 9 seismological stations. It operated successfully and gave advance notice of the impending arrival of the seismic sea wave of March 9, 1957 in the Hawaiian Islands. Arrangements have been completed to warn the civil defense authorities on the west coast of the United States, and travel time charts to permit the rapid estimate of the arrival times at five points on the West Coast have been computed.

Symposium: *Marine Upwelling—Physical and Chemical Aspects*

UPWELLING IN A BAROCLINIC OCEAN†

KOJI HIDAKA

Tokyo University, Tokyo, Japan.

(Abstract)

The equations of water motion in a baroclinic ocean is integrated and the velocity of upwelling determined in terms of horizontal pressure gradients (geostrophic flow) and prevailing wind stresses on the surface.

DISCUSSION

T.R. FOLSOM: Would it be possible and valuable to recalculate the results with electronic computers?

K. HIDAKA: It would be very valuable to do this, and the schemes are already prepared for calculating oceanic currents from geostrophic flow and wind stress.

K. WYRTKI: In the representations of the upwelling in the whole Pacific during the four seasons, the run of the isolines in all four charts is essentially smoother in the North than in the South Pacific. Is this an effect of the scantiness of the material in the South Pacific?

K. HIDAKA: I do not think so; it might be due to more complicated conditions in the South Pacific.

† A part of the paper was published in the *Geophysical Journal of the Royal Astronomical Society*, **1** (3) : 198-207, 1958 under the title of "Dynamical Computation of the Equatorial Current System of the Pacific, with Special Application to the Equatorial Undercurrent" by Koji Hidaka and Yutaka Nagata. The other part requires more work to be done and will be published in the future.

THE WATER EXCHANGE BETWEEN THE PACIFIC AND THE INDIAN OCEANS IN RELATION TO UPWELLING PROCESSES

KLAUS WYRTKI

Institute of Marine Research, Djakarta, Indonesia.

Investigations of the monsoon circulation in the Southeast Asian waters give evidence of a region of alternating upwelling and sinking in the Banda and Arafura Seas. During the southeast monsoon from May to September, the Monsoon Current flowing westwards in the Java and Flores Seas originates in the Banda Sea. Parts of the water masses are coming from the Pacific Ocean through the Halmahera Sea. But these are not sufficient to form the Monsoon Current. On the other hand, the Timor Current flowing into the Indian Ocean takes water out of the Arafura Sea. Because a considerable flow through the Torres Strait is impossible, the deficit of water must be compensated by upwelling in the Banda and Arafura Seas. Schematically the pattern of the surface flow is given in Fig. 1,a.

Nearly the opposite conditions are found during the northwest monsoon from November to March. The strong Monsoon Current coming from the Java and Flores Seas disappears in the Banda Sea. Only a part of the water masses leaves the region through the Halmahera and Molucca Seas, and another part is deflected into the Timor Current, which is relatively weak during this season. Therefore, considerable water masses must submerge in the Banda and Arafura Seas; see Fig. 1,b.

Hydrographic investigations in this region of upwelling and sinking were available only from the *Snellius* Expedition from October at the end of the upwelling season *(1)*. In 1957, the research vessel *Samudera* occupied a number of oceanographic stations in this region in March at the beginning of the upwelling season in order to have material for a comparison of the hydrographic conditions before and after the upwelling *(3)*.

The vertical distributions of temperature and salinity between the surface and 200 meters depth at six pairs of stations in the upwelling region are shown in Fig.2. The positions of the *Snellius* and the *Samudera* stations are given in the map of the same figure. The representations show clearly the ascending of the discontinuity layer during the southeast monsoon. In October, there is no homogeneous layer; the decrease of the temperature starts at the surface; the salinity is relatively high, and its variation with the depth is small. In March, before the beginning of the upwelling season, there exists a homogeneous layer of about 80 meters. The temperature is higher than in October; the salinity is lower within the whole homogeneous layer. In the western part of the region, the salinity is below $34^{\circ}/_{\circ\circ}$ and at station Sa 64, a top layer with very low salinity exists. Within the discontinuity layer at temperatures of about 20°C., the salinity maximum of the Subtropical Lower Water is seen at some stations.

A comparison of the hydrographic conditions during the two surveys shows the discontinuity layer being 50 to 70 meters higher in October than in March. Considering the duration of the upwelling season to be four months, a vertical upwards velocity of 0.6×10^{-3}cm/sec. results. The upwelling is restricted to the region shown in Fig.2, comprehending the eastern parts of the Banda Sea and the deeper western parts of the Arafura Sea. The large eastern parts of the Arafura Sea are mostly too shallow for these deep reaching processes. Therefore an area of 27.1° squares results for the horizontal extension of the upwelling region. With this areal and the calculated upwards velocity of the upwelling, an ascending water transport of 2 million m^3/sec. results. But this means that the region is able to give considerable supply to the Monsoon Current during the southeast monsoon and to take up the Monsoon Current during the northwest monsoon.

With these data it becomes possible to reconstruct the hydrographical processes active in this region. The temperature-salinity diagram in Fig.2 shows the characteristics of the different water masses. During the northwest monsoon a water mass of high temperature and low salinity enters the Banda Sea with the Monsoon Current coming from the Java Sea and spreading above the waters being present in the region. The discontinuity layer sinks down, and at the end of the sinking season the layer of warm, less saline water is about 80 meters thick. With the beginning of the upwelling season in May, the south-

east monsoon drives these waters of the homogeneous layer westwards and water of deeper layers reaches the surface. The surface water becomes gradually cooler and the salinity rises, which is also partly an effect of the high evaporation during the southeast monsoon. At the end of the upwelling season, the top of the thermocline reaches the surface. The temperature - salinity values at the surface coincide in October partly with those at the top of the thermocline. This means that the water masses of the homogeneous layer are completely removed. The salinities at the surface vary between 34.2 and 34.8°/$_{oo}$. Locally the salinity has a maximum at the surface due to the evaporation.

The alternating of a season with upwelling and a season with sinking is the real characteristic of this region. At first the processes above and within the discontinuity layer have been discussed, but the rising and sinking of the discontinuity layer in connection with the circulation in the surface layer must also influence the water movements below the discontinuity. According to the general oceanic circulation, the sea level in the

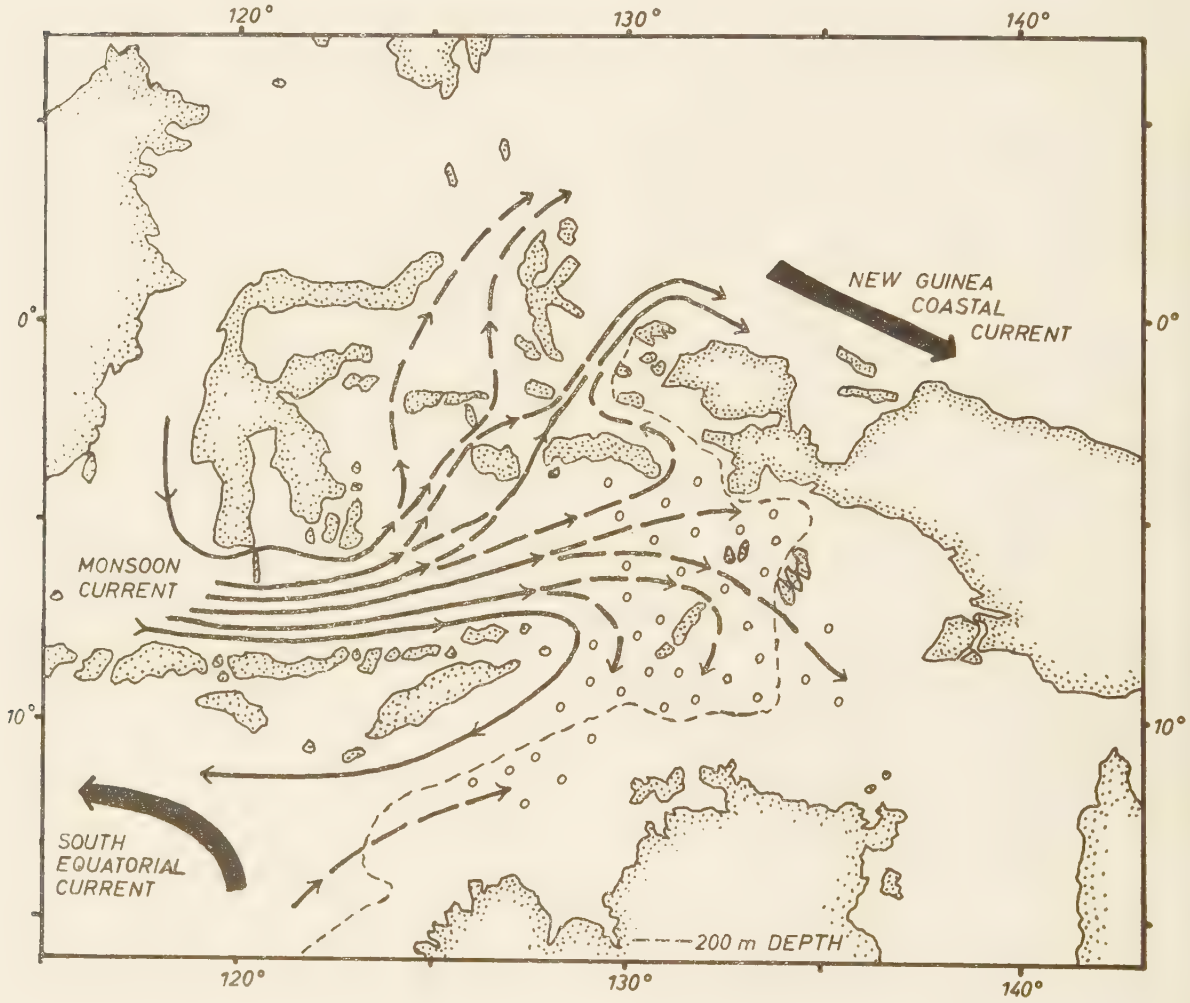


Fig.1,a. — Transports in the surface layer of the eastern parts of the Indonesian waters in February.
———— 1 Million m³/sec × × upwelling
— — — 0.5 Million m³/sec o o sinking

vicinity of the Phillippines is higher during the whole year than the sea level south of Java in the range of the South Equatorial Current. This fact requires a continual flow from the Pacific to the Indian Oceans.

During the southeast monsoon from May to September the South Equatorial Current of the Pacific Ocean is well developed north of New Guinea. Parts of its water flow through the Halmahera Sea into the Banda Sea and form the source of the Monsoon Current. But these water movements through the Halmahera Sea reach relatively deep, as the observations of the *Snellius* have shown. Beside the surface water, water of the discontinuity layer is transported southwards, containing the core layer of the Subtropical Lower Water with its salinity maximum. The influence of the increased salinity due to the spreading of the salinity maximum in a depth of about 150 meters reaches down to about 400 meters depth. This water mass enters through both sides of the island of Ceram, the Banda Sea and advances as far as Timor in a depth between 125 and 300 meters. It replaces the water masses rising to the

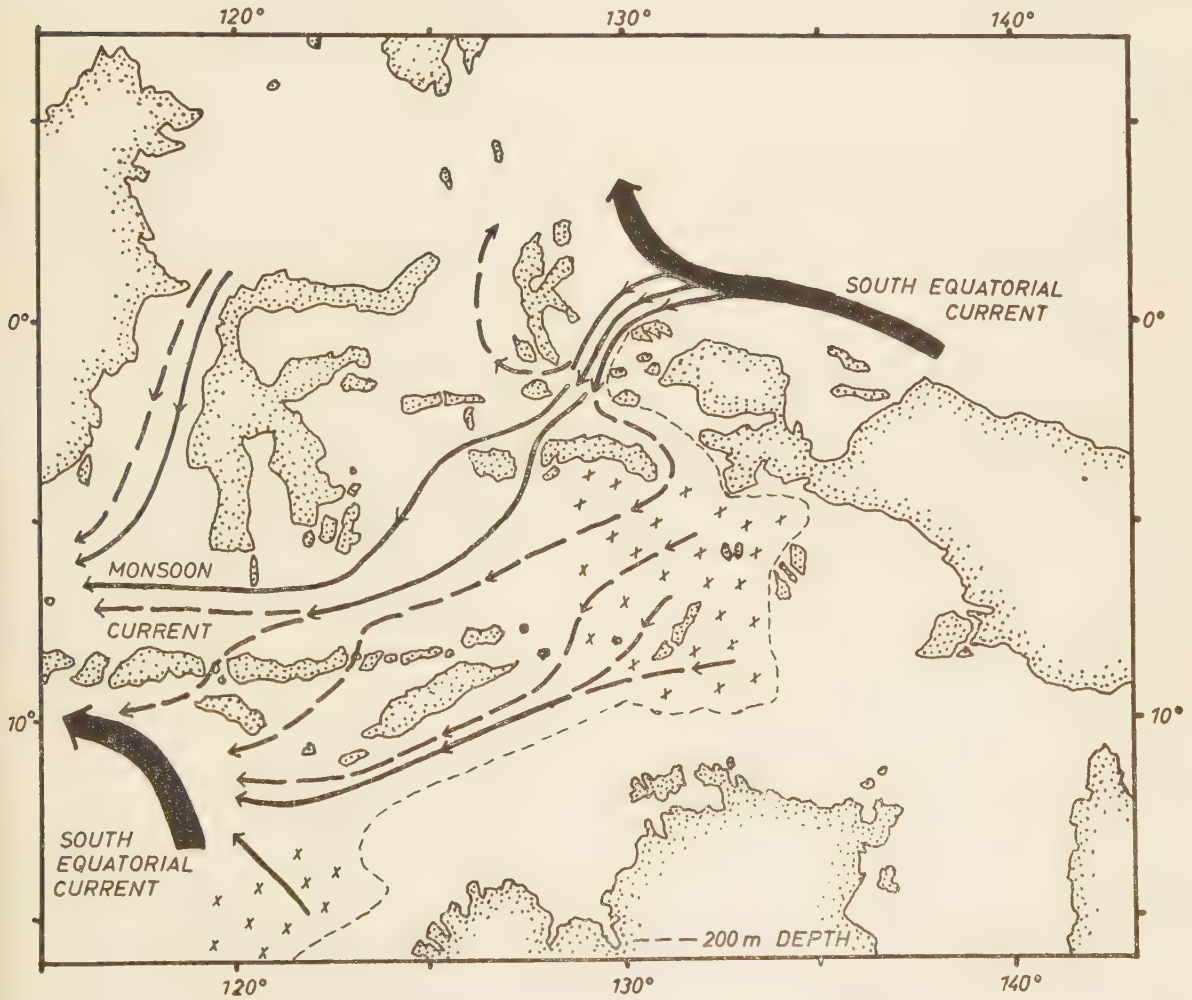


Fig.1,b. — Transports in the surface layer of the eastern parts of the Indonesian waters in August.
———— 1 Million m^3/sec × × upwelling
— — — 0.5 million m^3/sec o o sinking

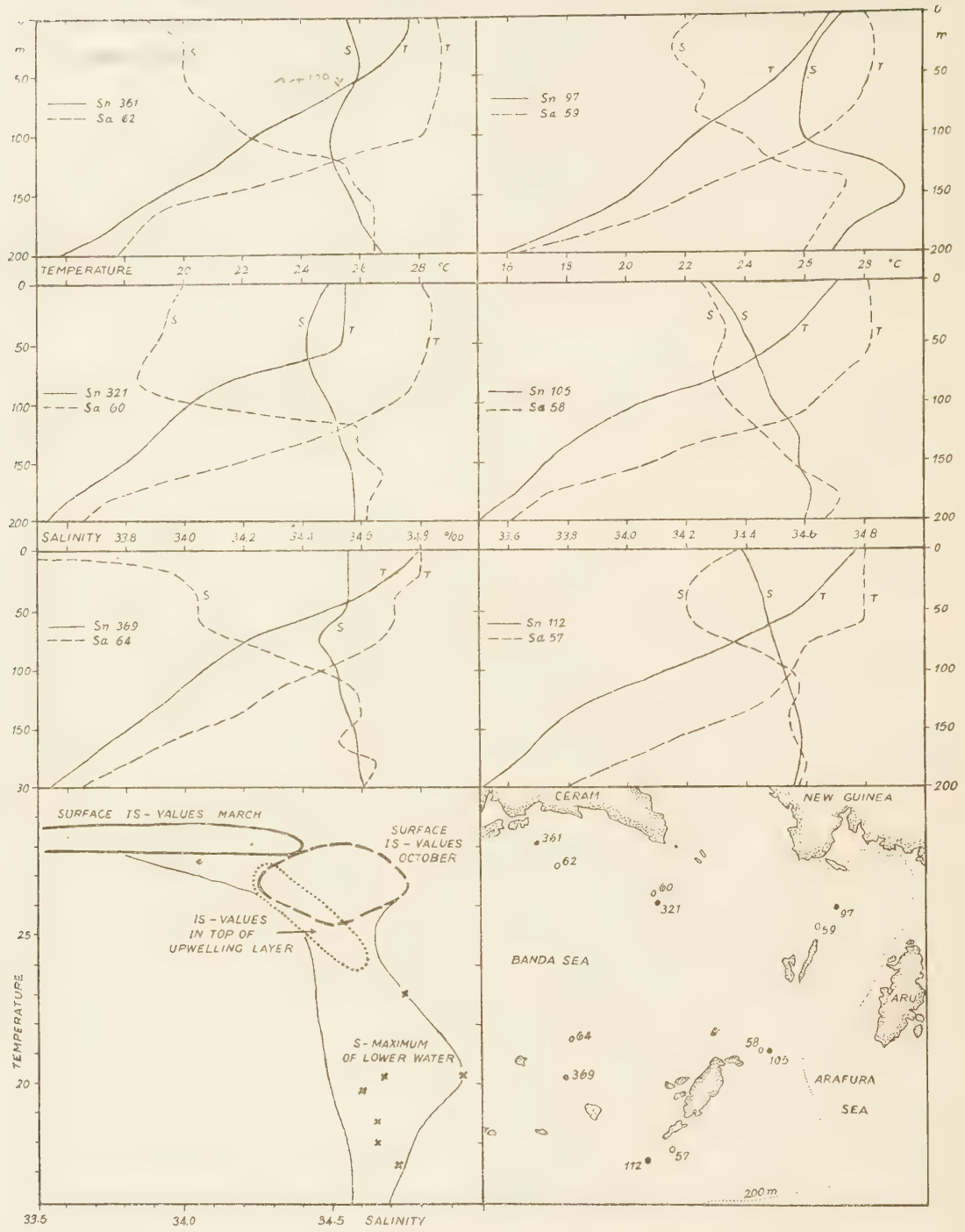


Fig. 2.— Hydrographic conditions in the upwelling region of the eastern Banda Sea and the Arafura Sea. Upper part: vertical distribution of temperature and salinity between the surface and 200 meters depth, comparing the observations of the *Snellius* in October, 1929, with those of the *Samudera* in March, 1957, at six positions. Stations are shown in the map right below. Lower part, left: temperature-salinity diagram of the region demonstrating the variation of the hydrographic conditions during the upwelling and sinking season.

surface by the upwelling processes and renews the water within the discontinuity layer.

On the other hand, during the northwest monsoon from November to March, the surface flow in the Halmahera Sea is reversed, and its water passes over into the New Guinea Coastal Current flowing eastwards along the north coast of New Guinea. It is likely that during this season the flow of the water in deeper layers comes to rest and no Subtropical Lower Water enters the Banda Sea. Consequently, the Subtropical Lower Water enters the Banda Sea only during the season of the southeast monsoon, when upwelling takes place, while during the northwest monsoon its flow is stopped.

The next question to prove is the whereabouts of the water masses during the period of sinking. There is no indication of a flow of water in deeper layers into the Pacific Ocean, and this, too, would be in contrast to the general circulation, as stated above, which requires a flow of water from the Pacific to the Indian Ocean. An analysis of the water masses of the eastern Indian Ocean, however, shows a layer of minimal salinity spreading in a depth of about 1,000 meters, and Sverdrup *(2)* believes this water to be of Pacific origin. A detailed examination of this water mass shows that it has the same characteristics as the water in the Banda Sea in 1,000 meters depth. This fact makes it likely that during the sinking period the water masses sinking down in the Banda Sea are compensated by a flow of water from the Banda Sea into the Indian Ocean in the 1,000 meter level. A complete analysis of these water masses will be published later by the author.

The examination of this upwelling and sinking region shows clearly the relations between the flow of water in the surface layer, the vertical movements, and the flow in the deep layers. This gives a good example for the opposite interaction of the surface and the deep circulation at the water exchange between the Pacific and the Indian Oceans under the influence of the seasonally changing monsoons.

Summarizing the results, two schematical representations are prepared, Fig. 3, to show the pattern of flow during the two monsoons. During the southeast monsoon, the Monsoon Current flowing into the Flores Sea and the Timor Current flowing into the Indian Ocean are supplied by water of the Banda and Arafura Seas. Because the inflow of surface water from the Pacific Ocean is not sufficient to balance the outflow, upwelling takes place. The upwelling water is replaced within the discontinuity layer by an inflow of the Subtropical Lower Water from the Pacific Ocean.

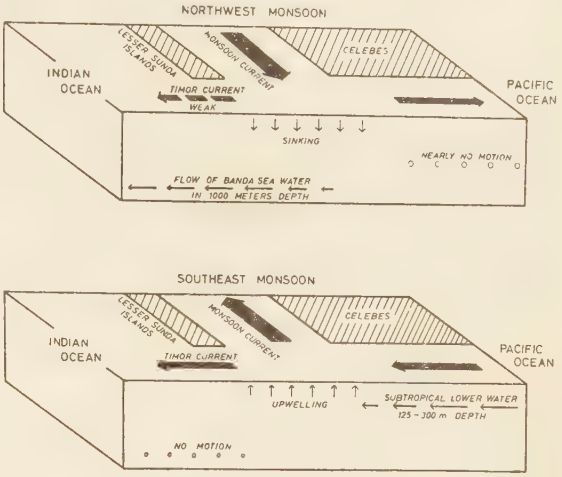


Fig. 3. —Schematical presentation of the flow of the different water masses in the water exchange between the Pacific and the Indian Oceans in two longitudinal sections for the two monsoon seasons.

During the northwest monsoon, the Monsoon Current coming from the Flores Sea splits off in the Banda Sea, one branch flowing into the Pacific Ocean, another branch passing over into the Timor Current, which is only weakly developed during this season. But the Monsoon Current is stronger than the outflow at the surface from the Banda Sea, and sinking of water masses occurs in the Banda and Arafura Seas. The sinking water is balanced in the depths by an outflow of Banda Sea water into the Indian Ocean in the 1,000 meter level.

These remarks demonstrate clearly the role of the upwelling and sinking region in the Banda and Arafura Seas for the water exchange between the Pacific and the Indian Ocean. This water exchange shows a remarkable seasonal effect. During the upwelling season an inflow of water from the Pacific Ocean occurs in intermediate layers into the region and during the sinking season an outflow of water in deep layers into the Indian Ocean. This means that below the surface layer there is always a flow from the Pacific to the Indian Ocean, but it takes place in different layers during both seasons. All of this is an example of the opposite interaction between the flow at the surface and in deeper layers in connection with vertical movements.

REFERENCES

(1) Riehl, P.M., van, a.o., 1950, *Serial and bottom observations*. The *Snellius* Expedition, **2,6**.

(2) Sverdrup, H.U., a.o., 1946, *The Oceans*. New York.

(3) Wyrtki, K., 1957, Oceanographic Station List. *Marine Research in Indonesia*, **3**.

DISCUSSION

D.J. ROCHFORD: Might it be possible to calculate the intensity of upwelling from sea level data?

K. WYRTKI: Sea level data can give only an additional evidence of the phenomenon of upwelling, but the use of them for calculating numerical values requires the complete theoretical solution of the upwelling process.

K. HIDAKA: Have relations been found to fisheries in the upwelling region?

K. WYRTKI: Fisheries are little developed in this region, and no comparable material is available.

A.L. TESTER: Are there any observations on nutrient enrichment in the region?

K. WYRTKI: Besides information from a few stations, there are no observations available, but these indicate richer water in and below the discontinuity layer, so that probably during the upwelling season water of higher nutrient content comes onto the euphotic zone.

VARIATIONS IN UPWELLING IN THE EQUATORIAL PACIFIC

THOMAS S. AUSTIN and MURICE O. RINKEL†

Pacific Oceanic Fishery Investigations, U.S. Fish and Wildlife Service, Honolulu, Hawaii.

The Pacific Oceanic Fishery Investigations (POFI) of the U.S. Fish and Wildlife Service has been investigating the tuna resources of the central equatorial Pacific since early 1950. This program has included a number of cruises to describe the physical and chemical environment of those important commercial fishes. Because of its biological importance, upwelling occurring along the Equator between the 180th meridian and 120° W. has received particular attention. Utilizing the results of these studies from the central and eastern Pacific and the available published data from the western Pacific, we shall discuss the east-west variations in upwelling.

For the purpose of this discussion, we shall define upwelling occurring at or near the Equator as the mixing of deeper, cooler, nutrient-rich waters with those at the surface, the underlying cause being a wind-induced divergence of the surface waters. We are assuming that, under conditions of steady easterly winds and a poleward increase in Coriolis Force (vanishing at the Equator), there is upward transport at the Equator, and then a poleward movement of the surface waters. At some distance from the Equator the surface waters sink and return equatorward in that part of the surface layer below the wind drift current (South Equatorial Current). Approaching the Equator this subsurface flow gains eastward momentum, flowing to the east as the Equatorial Undercurrent. The basic models for these circulation features are those described by Cromwell (*3*, p. 208) and Fofonoff and Montgomery (*6*, p. 519).

† The paper was read by Dr. A.L. Tester.

One index of upwelling along the Equator is the presence of cooler waters at the surface. Spatial and temporal variations in the temperature of these cooler waters may be considered to reflect variations in the degree of surface divergence and upward transport. In Fig. 1, modified from Schott (*11*, plate XXII), we show the surface isotherms for an area of 10 degrees to each side of the Equator extending across the Pacific. East of 180° longitude the configuration of the isotherms denotes cooler waters at the surface and the poleward warming of these waters. West of 180° the surface temperatures are strikingly uniform, at least within the contour interval, suggesting that upwelling is either absent or weakly developed.

Other indices of upwelling can be found in the distribution of physical and chemical properties along vertical sections crossing the Equator.

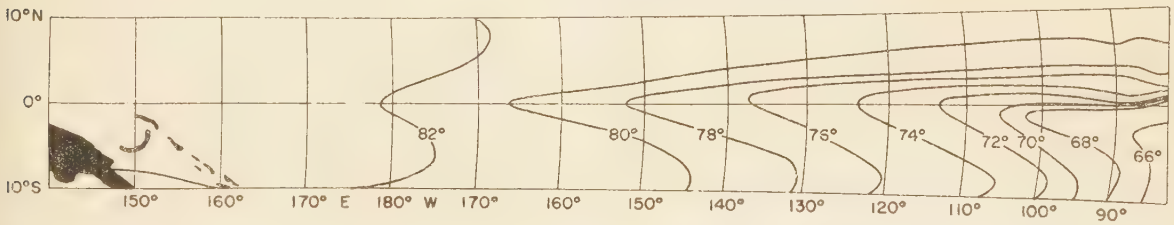


Fig. 1.—Surface temperature in Pacific Ocean in August (modified from *11*, plate XXII).

Twenty-five such transects between 180° and 110° W. have been accomplished on POFI cruises (*12* and M.L. Godfrey[1]). In addition to these sections resulting from oceanographic cruises, we have available a number of temperature profiles obtained on longline fishing cruises, together with useable direct measurements of flow of the mixed layer from the drift of tuna longline gear[2].

[1] In paper entitles "Review of POFI's Oceanographic Program, January 1952-June 1957," presented at the Ninth Pacific Science Congress. (see p. 18 in this volume)

[2] The longline gear, ordinarily fished at stations 60 miles apart, is allowed to drift freely for approximately 6 hours at each set; the direction of the drift normally provides information on the transport of the surface waters.

In Fig. 2 we have combined the data from the drift of the longline with the vertical temperature section from *John R. Manning* Cruise 18 along 155° W. *(13)*. The poleward divergence of the surface waters is shown by drift vectors. In the vertical temperature profile, the 78° F. isotherm intersects the surface on either side of the Equator and the upward transport is reflected by the domed isotherms.

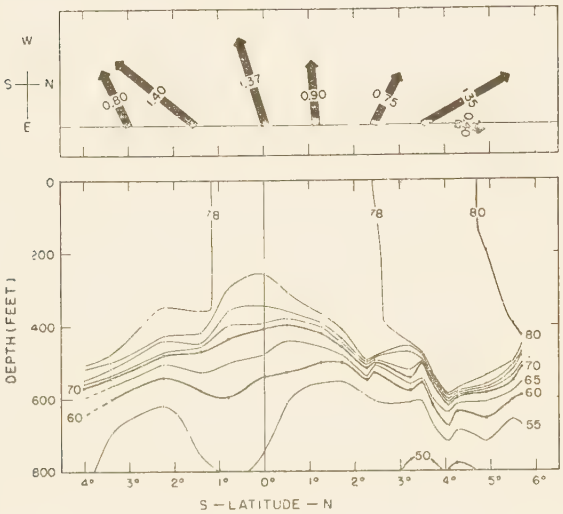


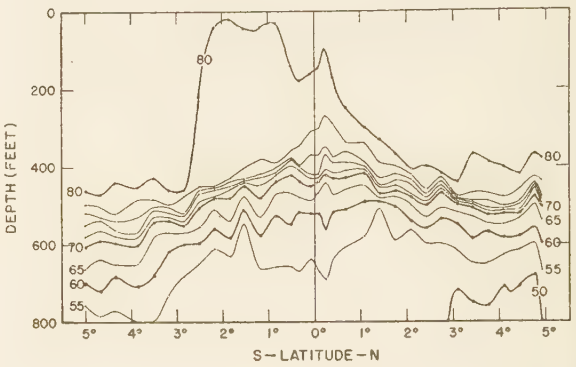
Fig. 2.—Upper panel: longline drift, *John R. Manning* Cruise 18, 155° W., December 2-12, 1953; vectors indicate the direction of the drift; numbers speed in knots.

Lower panel: temperature from BT data in °F., *John R. Manning* Cruise 18, 155° W., December 2-12, 1953; plotting interval 2° F. except as noted.

During POFI's oceanographic cruises, the concentration of inorganic phosphate is normally measured in surface and subsurface waters. The highest concentrations, between 0.80 and 1.00 μg at./l., are associated with the coolest surface temperature, and there is a decrease to the north and south of the divergence. In the vertical phosphate sections, there is a domed configuration of the isopleths that parallels the temperature variations *(1, 2)*.

In the southeastern Pacific, centered about 20° S. latitude, the salinity maximum occurs in the surface waters. These dense surface waters sink, flow northerly and then westerly. It would be reasonable to assume that in the central Pacific this subsurface tongue-like layer of high-salinity water might penetrate into the Northern Hemisphere. This does not happen, however. The northern extent of this subsurface layer is limited by mixing associated with the upwelling near the Equator.

In Fig. 3 we have shown the vertical temperature and salinity profiles from *Hugh M. Smith* Cruise 14 along 155°W. The previously described doming of the isotherms is evident. In the lower panel of Fig. 3, the subsurface salinity maximum is defined by shading. It is apparent that the northern extent of this feature does not extend beyond the Equator.



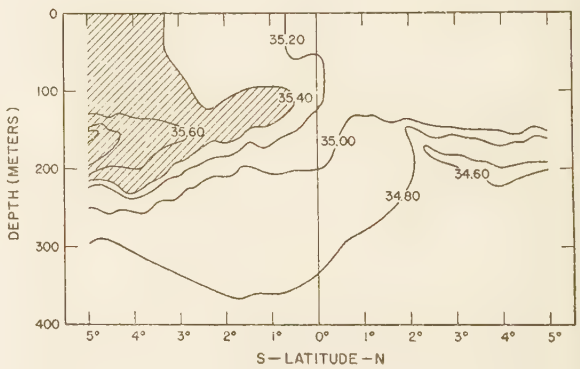


Fig. 3.—Upper panel: temperature from BT data in °F., *Hugh M. Smith* Cruise 14, stations 1-16, 155° W., longitude, January-February, 1952; plotting interval 2° F. except as noted.

Lower panel: salinity in parts per mille, *Hugh M. Smith* Cruise 14, stations 1-16, 155°W. longitude January - February, 1952; plotting interval 0.2°/$_{oo}$.

Using the previously defined criteria for upwelling, we have inspected a number of published vertical temperature and salinity sections from the western Pacific. In Fig. 4 we reproduce two temperature sections along 164° E. and 167° E. from Robinson *(10)*. In neither section, with

2-degree contour intervals, is there evidence of cooler water at the surface, as might be indicated by the intersection of the isotherms with the surface to each side of the Equator. In the mixed layer there are no significant meridional variations in temperature. In addition, there is no doming of the subsurface isotherms near the Equator.

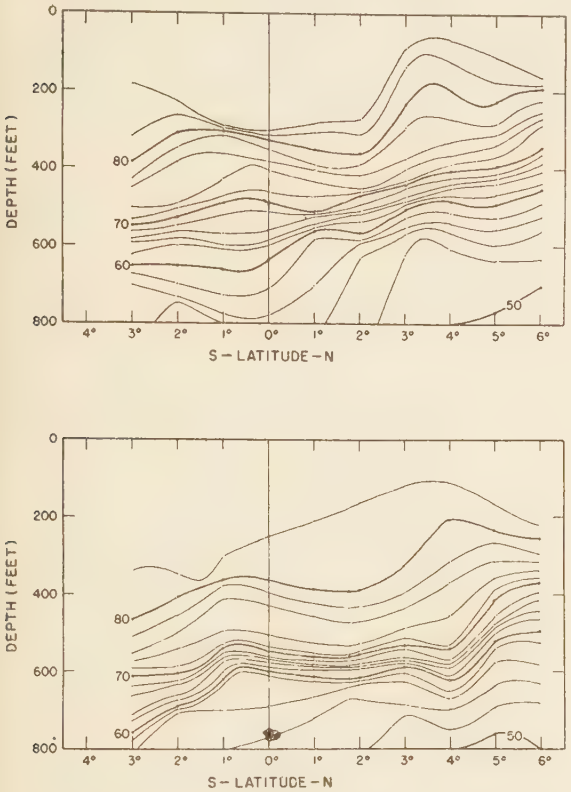


Fig. 4.—Upper panel: temperature from BT data in °F., U.S.S. *Barton, (10)*, 164° E., July, 1946; plotting interval 2° F.

Lower panel: temperature from BT data in °F., U.S.S. *Laffey (10)* 167°E., July, 1946; plotting interval 2° F.

In the western Pacific, the subsurface tongue of high salinity penetrates into the Northern Hemisphere reaching to 4° N., as shown in the two sections in Fig. 5 *(7)*. Fig 5, upper panel, is a composite of the data from four sections (March-August, 1946) across the Equator near 166° E. longitude. The lower panel is a composite of many sections taken during 1933 to 1941 in an area centered around 164° E. longitude. Comparison of the northern limits of the intermediate salinity maximum in the western Pacific (Fig. 5) with that in the central Pacific (Fig. 3, lower panel), indicates that if any upwelling were present, it was ineffective in limiting the penetration of the maximum into the Northern Hemisphere.

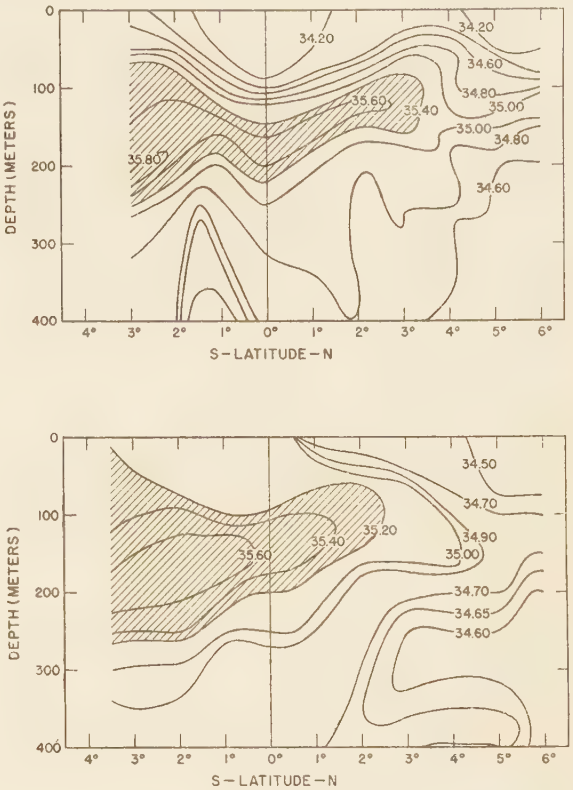


Fig. 5.—Upper panel: salinity in parts per mille, Crossroads data *(7)*, 166° E., March-August, 1946.

Lower panel: salinity in parts per mille, Japanese data *(7)*, 164° E., summer season, 1933-1941.

In the introduction we stated the assumption that upwelling occurs under a condition of steady easterly winds. It is known that the easterly component of the trades is a variable, both in space and time. We shall now make the further assumption that variations in upwelling are related to variations in the easterly components of the trades.

Meteorological data from the equatorial Pacific are scarce, and it is difficult to derive more than a general picture of the surface wind flow. Palmer *(8)* Dean *(5)* and Riehl *(9)* have used streamline analysis as a method of showing variations in the wind direction and have included the isovels on their charts. These analyses show that the winds along the Equator between approximately 140° W. and 170° W. are predominantly

from the east throughout the year. This is the general region of persistent upwelling as revealed by our data. To the west of this region, as the easterly components of the wind gradually decrease, there must be a corresponding decrease in the divergent flow of the surface waters at the Equator, approaching a convergent flow under conditions of westerly winds *(3)*. Palmer (*8*, p. 876) states that "in both the wet (summer) and dry (winter) seasons there is a *mean west wind on the Equator in the western part of the ocean.*"

We recognize that there are other mechanisms which result in the presence of cooler, enriched surface waters at or near the Equator. In the eastern Pacific, the thermocline is very near the surface, sloping upward from a depth of 150 to 200 meters near 160° W. to 50 meters or less near 120° W. (T.S. Austin[3]). This situation, comparable to the thermal anticline described by Cromwell *(4)*, brings the thermocline under the influence of direct wind mixing. Considering that the winds in the far eastern Pacific are more southerly than easterly, the proximity of the thermocline to the surface and wind mixing may play a more important role in bringing cooler waters to the surface than divergence and upwelling.

The easterly flowing Equatorial Undercurrent underlies the westerly wind-driven South Equatorial Current. The interface of these two opposing currents is in the mixed layer; and the mixing associated with the resulting shear must play an active, quantitatively undetermined role in the processes which result in cooler waters on the surface at the Equator.

Thus, from the available data, we have shown that there are variations in upwelling along the Equator in the Pacific. The most persistent and pronounced upwelling is to be found in the eastern and central Pacific, decreasing or being absent in the western Pacific. In the eastern Pacific, other mechanisms in combination with upwelling, produce the measurable factors in the surface subsurface waters which were chosen as indices of upwelling.

REFERENCES

(1) Austin, T.S., 1954a, Mid-Pacific Oceanography III: Transequatorial Waters, August-October 1951, *U.S. Fish and Wildlife Service, Spec. Sci. Rept.* (*Fish.*), **131**: 51 pp.

(2) — ——, 1954b, Mid-Pacific Oceanography V: Transequatorial Waters, May-June 1952, August 1952, *U.S. Fish and Wildlife Service, Spec. Sci. Rept.* (*Fish.*), **136**: 86 pp.

(3) Cromwell, T. 1953, Circulation in a Meridional Plane in the Central Equatorial Pacific, *Jour. Mar. Res.* **12** (2): 196-213.

(4) ———, 1956, EASTROPIC Expedition: What it Seeks, and Where It Fits into Practical Industrial Fishing, *Pacific Fisherman*, **54** (8): 25, 27, 29.

(5) Dean, G.A., 1954, A Synoptic Explanation of the Climatological Divisions in the Central Pacific during the October Season, Oahu Research Center, Inst. Geophysics, *University of California, Scientific Rept.* **7** [Contract No. AF 19 (604) - 546]: 16 pp.

(6) Fofonoff, N.P. and Montgomery, R.B., 1955, The Equatorial Undercurrent in the Light of the Vorticity Equation, *Tellus*, **7** (4) : 518-521.

(7) Mao, Han-Lee and Yoshida, K., 1956, Physical Oceanography in the Marshall Islands Area, *U.S. Geological Survey Professional Paper*, **260 - R** : 645 - 684.

(8) Palmer, C.E., 1951, Tropical Meteorology, *Compendium of Meteorology*. Boston: American Meteorological Society. 859-880.

(9) Riehl, H., 1954, *Tropical Meteorology*. New York: McGraw - Hill Book Co., Inc. 392 pp.

(10) Robinson, Margaret K., 1954, Sea Temperature in the Marshall Islands Area, *U.S. Geological Survey Professional Paper*, **260 - D**: 281-291.

(11) Schott, G., 1935, *Geographie des Indischen und Stillen Ozeans*. Hamburg: Verlag von C. Boysen. 413 pp.

(12) Sette, O. E. and the Staff of POFI, 1954, Progress in Pacific Oceanic Fishery Investigations, 1950-53, *U.S. Fish and Wildlife Service, Spec. Sci. Rept.* (*Fish.*), **116:** 75 pp.

[3] Unpublished manuscript, "Oceanography of the East-Central Equatorial Pacific as Observed during Expedition Eastropic," Pacific Oceanic Fishery Investigations, Honolulu. T.H.

(13) Shomura, R.S. and Murphy, G.I., 1955, Longline Fishing for Deep-Swimming Tuna in the Central Pacific, 1953, *U.S. Fish and Wildlife Service, Spec. Sci. Rept. (Fish.)* **157:** 70 pp.

DISCUSSION

R.W. HIATT: What factor causes the change of the condition at 180°?

A.L. TESTER: This is probably an effect of the change of the wind direction from predominately easterly to southeasterly winds. It is surprising that the Equatorial Undercurrent is not recognizable by a stronger uniting in its range, in spite of its strong velocity.

T. CROMWELL: The data on the undercurrent are still scanty, especially the direct current observations, and further observations are required.

A discussion between Dr. Tester, Dr. Rochford, Dr. Cromwell, and Dr. Wyrtki, arose, in which it was pointed out that an exact definition of the term "upwelling" would be desirable in order to avoid confusion. It seems that too many different effects and phenomena are named as "upwelling."

THERMOCLINE TOPOGRAPHY, HORIZONTAL CURRENTS AND "RIDGING" IN THE EASTERN TROPICAL PACIFIC†

TOWNSEND CROMWELL‡

Inter-American Tropical Tuna Commission, Scripps Institution of Oceanography, La Jolla, California, U.S.A.

(Abstract)

Thermocline depth has been read from all bathythermograph observations in the eastern Tropical Pacific. Charts showing the thermocline topography are presented. A persistant thermal anticline, a shallow thermocline, is described and its relation to currents discussed. Physical differences which distinguish a thermal anticline from a region of upwelling, are described. Charts of surface current, along with those of thermocline topography, show that the Equatorial Countercurrent probably does not exist in the eastern Tropical Pacific during the Northern Hemisphere winter.

DISCUSSION

J.H. RYTHER: Could not the enrichment of the surface water above the thermocline result from the diurnal migration of plankton organisms, which feed in the rich thermocline waters and then swarm upward and excrete organic matter in the warm surface layer, where it is quickly mineralized?

T. CROMWELL: Yes, it could be important. The relative importance of enrichment processes at the dome are not really known yet.

K. WYRTKI: By means of a diagram, showing the temp.-phosphate relation of the water, it could be decided whether or not a heading of the water of high phosphate content occurs. The values of the upwelled water had to be found at higher temperatures and phosphate contents.

T. CROMWELL: This idea has already been tried in analyzing the observations and seems to be successful.

A.L. TESTER: Will vertical mixing induced by wind not cause variability in any chemical relationship between T and P at the dome?

T. CROMWELL: Yes, to some extent.

A.L. TESTER: Vertical mixing seems to play an important part in enrichment to the west of the dome. Do you agree?

T. CROMWELL: Yes, sporadically, the system described for the dome does not apply further west, where the thermocline is somewhat deeper.

A.F. Bruun suggested that any conclusion drawn from observations on the phosphate be closely considered in the light of simultaneous biological observations on the zooplankton.

†Published in the *Bulletin of the Inter-American Tropical Tuna Commission*, 3(3), 1958.

‡Mr. Cromwell was killed in an airplane crash in Mexico in June, 1958.

A STUDY ON UPWELLING

KOZO YOSHIDA

Geophysical Institute, Tokyo University, Tokyo, Japan.

INTRODUCTION

Upwelling is induced by a horizontal divergence of the horizontal component of flow, which in most cases is generated by surface winds. Hence the vertical motion may respond to the wind action without time lag larger than a few days. In contrast, horizontal currents themselves are nearly geostrophic and vary with mass distributions which include some integral effects of winds. Vertical motion will cause the changes in mass distributions and consequently those in geostrophic currents, but these geostrophic currents are nearly non-divergent so that they may not alter the wind-generated vertical motion appreciably. In the lower layers, motions may be considered essentially not wind-driven but are induced by the changes in pressure field as a consequence of the horizontal divergence in the surface layer, and they occur so as to compensate the surface divergence in the upper layer.

These considerations may lead to the idea that the vertical motion can be determined from either wind or density distributions, or from a combination of these two. Obviously, the methods to estimate the vertical motion, which are based on dynamics involved, should depend largely upon the scale of processes concerned. Two typical examples of the determination of upwelling of different scales have so far been presented by the present author and, these seem to show satisfactory agreement between theory and observations.

In this article, only a summary of the present study will be given, and more detailed discussion will be published in another paper.

RESPONSES OF TWO-LAYER OCEAN TO VARIABLE WINDS

The basic ideas of the discussions contained in this paper may simply be derived from a theory of dynamical responses of two-layer ocean to variable winds.[1] The dynamical model here assumed is essentially the same as that treated by Veronis and Stommel *(5)*, Charney *(1)*, and the present author *(7)*. By confining our present interest to the variations of the periods longer than a few days, we can gain much simplification of the whole discussion. Then the vorticity equations in the upper and lower layers yield the two equations, of which one gives the deviation of the interface between the two layers in response to the forcing function, the wind stress vorticity applied at the sea surface. The other equation gives the relation between the deviations at the sea surface and at the interface.

Various simplifications of the equations which may correspondingly lead to various methods of determination of vertical motion can be made by assuming a criterion that the terms can be neglected if their magnitudes are less than, say, 10% of the main terms in balance. This determines the ranges of L and T for which the approximations are valid, where L is the wave length and T is the period of the variations under consideration.

Particularly let us call our attention to the two ranges[2] which correspond to certain large-scale processes (Range 1) as described in Section 3 and to small-scale processes (Range 2) as in Section 4. The analysis indicates that the approximation for Range 1 will be valid, if (1) the period

† Presented by Dr. Koji Hidaka.

1 The numerical values which result from the dynamics depend upon those assumed for various parameters, which are taken in the present study as

$$f = 10^{-4}\ \text{sec}^{-1},\quad \beta = 2 \times 10^{-13}\ \text{cm}^{-1}\ \text{sec}^{-1},\quad H_1 = 10^4\ \text{cm},\quad H_2 = 2 \times 10^5\ \text{cm},\quad \frac{\Delta\rho}{\rho_2} = 2 \times 10^{-3}$$

where f is the Coriolis parameter, $\beta = df/dy$, y being the horizontal coordinate directing northward, H_1 is the equilibrium thickness of the upper layer, H_2 is the one of the lower layer, and $\Delta\rho = \rho_2 - \rho_1$, ρ_1 and ρ_2 being the densities of the upper and lower layers respectively.

2 The approximations for Range 1 tell that horizontal divergence is balanced by wind stress curl in the upper layer and by planetary vorticity in the lower layer. Range 2 corresponds to the balance between horizontal divergence and time change in relative vorticity.

is longer than nearly one month, and if (2) the wave length is longer than the value as listed in Table 1 for different periods. The variations of periods shorter than one month or those of wave length less than 1000 km. should then be out of validity of this approximation.

Table 1.

T (in sec.)	2.6×10^6	0.8×10^7	3.2×10^7
	1 month	3 months	1 year
L (in km.) longer than	8000	2500	1300
T (in sec.)	6.4×10^7	1.61×10^8	2.2×10^8
	2 years	5 years	7 years
L (in km.) longer than	2600	6400	9100

Validity for Range 2 approximation will be secured, under the same criterion, if the period is between 7 days and 25 days, and if the wave length falls within the ranges as shown in Table 2. The wave length is limited between 24 km. and 330 km.

Table 2.

T (in sec.)	6.5×10^5	1.3×10^6	2.0×10^6
	1 week	2 weeks	3 weeks
L (in km.)	26 - 300	52 - 150	80 - 100

Another importance in this basic theory might be that relationship between changes in mean sea level and those in the vertical motion is obtained. This might give us a rough idea of the possibility of the determination of vertical motion from tide gauge recording at coast or island stations.

AN EXAMPLE OF LARGE-SCALE UPWELLING

Discussion in this section is concerned with the scale as large as classified in Range 1. Table 1 shows that annual variations in vertical motion forced by those in wind stress curl of which wave lenght is nearly 1000 km. will belong to this range. The annual variations in the vertical motion off California, when structure of scale smaller than 100 km. and one month is smoothed out, are the examples. Indeed, a study by the present author and Mao (1954, unpublished) indicated that the vorticity balance seems to be valid well in the California waters. It was found from the observed data there, that density of water at depths of 100 to 150 meters increases from month to month in the cases when geostrophic northward (poleward) flow is present in lower layers and that it decreases when subsurface flow directs southward (or equatorward). At the same time, it was pointed out that seasonal shift of the regions of ascending motion off the coasts appears to coincide well with the shift of the regions of positive wind stress curl over the area. These facts which indicated satisfactory agreement between theory and observations would support the validity of our dynamical model and suggests strongly a possibility of determining the large-scale features of vertical motion in certain oceanic area. Under the assumption of the similar relationship between the steady meridional components of deep geostrophic flow and horizontal mass divergence, Strommel *(4)* has determined the depth of no meridional motion for a particular oceanic area.

It might be worthwhile at this opportunity to comment on some remarkable features of isotherms or isopycnals which are frequently encountered especially in coastal regions where upwelling takes place. In examining the NORPAC temperature profiles, M. Uda[3] has paid particular attention to a "vertical divergence" of isotherms at depths between 200 m. and 500 m., revealed on a few east-west sections close to the Pacific coasts of North America. Defant *(2)* presented a similar type of isothermal pictures along the western coasts of North Africa and of South Africa. Such a feature might give an impression that onshore flow in a certain subsurface layer, as it strikes the coast, gives rise to upwelling in the layer above and sinking in the layer below. However, an alternative interpretation which seems more acceptable might be that the fall of isotherms toward the coast in the layers over several hundred meters above the 1000 meter level should indicate the presence of northward current at and somewhat above these depths as usually known by the name of California Countercurrent. Then the present theory requires that upward motion is present also in the lower layers, contrary to the sinking features of isotherms, to compensate the upwelling in the surface layer.

AN EXAMPLE OF COASTAL UPWELLING

It was empirically indicated that significant upwelling is likely to have taken place off the California coasts when the northerly wind blows along the coasts with duration as long as a week to several weeks. This upwelling is a kind

[3] Personal communication.

of boundary phenomenon which differs materially from the upward motion described above and is not considered purely wind-driven. In actuality, conspicuous upwelling which has been described off California is likely to be a process confined within small distance such as 100 km. from coasts. The coastal barrier and the stratification of water are essential to cause such a concentration of upwelling in narrow zone. This local but very important process of coastal upwelling belongs to the Range 2 stated in Section 2. A simple theory which appears to account for the process indicates that the speed of upwelling at the coasts is proportional to the wind stress and the width of upwelling zone depends upon latitude and stratification of the water *(6)*.

A question may arise whether or not strong offshore winds might also cause a significant upwelling along the coast. This problem must be of practical importance and is discussed in the first place. The approximate upwelling velocity at the coast is, when one considers the wind stress component normal to the coast in addition, given by[4]

$$\omega_H = \frac{1}{\sqrt{gH_1 \Delta \rho}} \left(\tau_y + \frac{1}{f} \frac{\partial \tau_x}{\partial_t}\right)$$

In the result, upwelling velocity due to the increase in offshore winds is smaller by one order of magnitude in ordinary conditions than that due to the wind parallel to the coast, although it could still be quite significant, giving about 1 meter per day for $|\partial \tau_x / \partial_t|$ of order of 10^{-5} cm^2. sec^{-3}. In the second place, annual variations in coastal upwelling is examined. Such variations are modified by the effect of planetary vorticity and do not belong to Range 2. In practice, however, the upwelling velocity at the coast is the same as the one for shorter periods if the amplitude of wind stress variations is the same. The only slight difference is that the width increases by 15 per cent and that vertical motion shows a lag of phase by one month.

There is a possibility that lateral mixing process may play a significant role in this case to reduce the amplitude and phase lag of the change appreciably. The observed annual changes in mean sea level along the Pacific of North America *(3)* might be explained well by applying this theory if we assume an additional role of lateral mixing by taking lateral eddy viscosity to be 10^5 to 10^6 cm^2. sec^{-1}. Should this be the case in reality, the tide gauge recording would give very useful means to measure the vertical motion in subsurface layers for the areas. In the third place, definite means should be given to estimate the value of $\sqrt{gH_1 \Delta \rho}$, although it is measurable and nothing of uncertain quantities like eddy viscosity and although errors due to this would be only a small matter of a factor of two or three. A difficulty may be encountered especially in coastal waters where the upper mixed layer is extremely thin or is absent. The best way perhaps will be that a depth where vertical density gradient is largest may be taken as H_1. An alternative method might be to measure the distance L, if possible, based on observed data of density change. Another way might be to measure the characteristics of long internal waves as is the speed of propagation of such waves in the area concerned.

Upwelling is of great importance to the productivity of waters because it brings nutrient salts into the euphotic zone. It might be desired to define upwelling in its proper sense by large upward transport of water from some deep layers into the surface layer. An occurrence of such a significant overturning of layers would require the upward displacement of water as large as the order of 100 meters at least. The duration of upwelling is only days in some cases and is months or could be many years in some other cases. It might be considered that the magnitude $|h|$ on the model given in the Section 2 gives a rough measure of the maximum amount of vertical shift of the thermocline so that this would give a very rough idea of the possibilities of occurrence of upwelling on different scales of the variations.

Assumptions are made in computing $|h|$ from the theory that (1) the variations are represented by waves of a form $\exp\left[i\left(\frac{2\pi}{T}t - \frac{2\pi}{L_x}x\right)\right] \sin\frac{2\pi}{L_y}y$ and that *(2)* the magnitude of wind stress curl is given by $\sqrt{\left(\frac{2\pi}{L_x}\right)^2 + \left(\frac{2\pi}{L_y}\right)^2} \left| \Pi(T, L_x, L_y) \right|$ where $|\Pi(T, L_x, L_y)|$ denotes the magnitude wind stress vector for various periods and wave lengths and is put here equal to 1 dyne cm.$^{-2}$ for all periods and wave lengths.

In actuality, there is a possibility that the lateral mixing effect may emerge perhaps for longer periods. However, the present result shown in Table 3 gives the values of $|h|$ based on the model which is free from the unknown effect of lateral mixing.

[4] ω_H is the vertical velocity, positively downward; τ_y is the component of wind stress parallel to the coast, positively northward, and τ_x is that normal to coast, positively onshore.

Table 3. $|h|$ in meters

(1) $L_y = 6000$ km.

$T \diagdown L_x$	12000km.	6000km.	600km.	60km.
∞	500	250	250	250
10 years	45	42	170	220
1 year	5.0	5.0	42	100
1 month	0.4	0.4	4.2	13
1 week	0.1	0.1	1.0	3.3

(2) $L_y = 600$ km.

$T \diagdown L_x$	12000km.	6000km.	600km.	60km.
∞	500	250	250	250
10 years	450	420	170	220
1 year	50	50	42	100
1 month	4.2	4.2	4.2	13
1 week	1.0	1.0	1.0	3.3

(3) $L_y = 60$ km.

$T \diagdown L_x$	12000km.	6000km.	600km.	60km.
∞	5×10^4	2.5×10^4	2500	250
10 years	1600	1600	1000	200
1 year	1700	170	160	70
1 month	14	14	14	8
1 week	3.3	3.3	3.3	2

For the coastal upwelling as described in section 4, $|h|$ is appreciable even for the period as short as a few weeks. (see Table 4)

Table 4. $|h|$ in meters

Period.	1 week	1 month	2 months	3 months
h at coast	10	40	84	126

If we disregard the lateral mixing effect, $|h|$ for the annual variations amount to 500 meters. Summarizing the above calculations, it follows that a significant amount of vertical displacement of water will not occur for variations of periods shorter than a year except for the coastal regions. Upwelling of practical importance would have the greatest chance to occur in coastal waters. There are some other mechanism of generating and maintaining upwelling under different conditions in different areas of the oceans. However, as far as our model is concerned, intense upwelling of duration as short as weeks to months would not occur in the open ocean.

REFERENCES

(1) Charney, J. G., 1955, The Generation of Oceanic Currents by Wind, *J. Mar. Res.* **14** (4): 477-498.

(2) Defant, A., 1936, *Das Kaltwasserauftriebsgebiet Vor der Küste Südwestafrikas.* Landerkundliche Forschung, Festschrift Norbert Krebs zur Vollendung 60 Lebensjahres dargebracht, 52-66.

(3) Pattullo, J., Munk, W.H., Revelle, R.R. and Strong, E., 1955, The Seasonal Oscillation in Sea Level, *J. Mar. Res.*, **14** (1): 88-155.

(4) Stommel, H., 1956, On the Determination of the Depth of No Meridional Motion, *Deep Sea Res.* **3:** 273-278.

(5) Veronis, G. and Stommel, H., 1956, The Action of Variable Wind Stresses on a Stratified Ocean, *J. Mar. Res.*, **15** (1): 43-75.

(6) Yoshida, K., 1955, Coastal Upwelling off the California Coast, *Records of Oceanographic Works in Japan.* **2** (2): 8-20.

(7) ————, 1956, A Note on the Pressure Changes of the Two-Layer Ocean, *J. Oceanogr. Soc. Japan*, **12** (4): 111-116.

SOME ASPECTS OF UPWELLING IN THE GULF OF PANAMA†

MILNER B. SCHAEFER, YVONNE M. M. BISHOP and GERALD V. HOWARD‡

Inter-American Tropical Tuna Commission, Scripps Institution of Oceanography, La Jolla, California, U.S.A.

(Abstract)

During the period of northerly winds from about November through March each year, there occurs strong upwelling in the Gulf of Panama, which has a striking influence on the physical, chemical and biological properties of the waters of the Gulf. The seasonal changes in +, S, O_2 and PO_4 have been measured by vertical casts at a station in the Gulf occupied every two weeks. At the same time, measurements have been made of the standing crops of phytoplankton and zooplankton. These data illustrate the effects on the biota of the upwelling phenomena.

Associated with the upwelling is a seasonal decrease in surface temperature and in sea level at Balboa. Records of temperature and sea level taken over the last fifty years by the Panama Canal Company have been studied. These indicate certain long-term trends, and also give some evidence of cyclic variations of about six or seven years.

DISCUSSION

Dr. G.E.R. Deacon asked weather the drop of the sea level during the upwelling season could be due to the change in density. An approximate estimation of this effect showed that the changing density would cause the observed change in the sea level, but it is not said that this is the reason, because the dynamic effect of the wind has to be considered also.

Dr. A.F. Bruun pointed out that biological investigation should always go hand in hand with investigations of upwelling. This could lead to biological identification of certain water bodies.

† Published in the *Bulletin of the Inter-American Tropical Tuna Commission*, 3 (1) 1958.

‡ Presented by Dr. R. Revelle.

UPWELLING IN THE PERU AND GENGUELA CURRENTS

G.E.R. DEACON

National Institute of Oceanography, Wormley, Godalming, Surrey, England.

(Abstract)

The physics of these currents is as difficult as the biology; most of the observations emphasize their variability in almost every particular. The northward current and the upwelling may prove to be dynamical consequences of wind stress far out over the ocean as well as of the local winds. The most urgent needs are for quantitative studies of the interchange of heat with the atmosphere as well as the horizontal and vertical exchanges of water.

DISCUSSION

T. CROMWELL: What is the reason for the strong oxygen consumption near the bottom of the Gulf?

G.E.R. DEACON: It is due to a decomposition of organic matter sinking to the bottom.

UPWELLING ALONG THE COAST OF PERU

E. SCHWEIGGER†

Lima, Peru.

(Abstract)

From a study of surface temperature, certain conclusions about the intensity and causes of upwelling in Peruvian waters have been deduced.

From Cabo Blanco to Aguja Point, Peru coastal current is wide offshore, and strong upwelling is generally absent. From Aguja Point to south of Puerto Chicama, the steepness of the continental slope facilitates lateral movement and upwelling of bottom waters. From Puerto Chicama to San Gallan Island, upwelling is very variable, and the deep waters can be prevented from moving to the surface by a very high temperature surface layer in coastal waters. From San Gallan Island to south of Atico, upwelling is most strongly developed in conjunction with a belt of trade winds. From south of Atico to Tocopilla, upwelling is reduced in intensity.

† Abstract prepared by Dr. D. J. Rochford, Chairman of the Standing Committee on Oceanography.

UPWELLING IN THE BAY OF BENGAL

E.C. LAFOND

U.S. Navy Electronics Laboratory, San Diego, California, U.S.A.

(Abstract)

Data collected between 1952 and 1956 along the western side of the Bay of Bengal[1] demonstrate the occurrence of upwelling all along the Indian coast from Madras to the Hooghly River. Near shore, surface manifestations of upwelling are (1) a rapid drop in temperature, (2) an increase in salinity, (3) an enrichment of plant nutrients, and (4) an increased production of plankton.

Upwelling in this area is attributed to the presistent southwest monsoon winds which blow nearly parallel to the coast from February to September. Under these conditions (1) the sea-surface next to the coastal barrier is lowered, (2) the surface current is directed to the northeast with an offshore component, and (3) the bottom currents have an on shore component, the results of which produce a zone of upwelling.

The vertical components of the circulation can be traced by the progressive upward displacement of isopycnals at the onset of upwelling in spring. At the same time the phosphate, nitrate, and silicate content of the water also undergoes a vertical transition near the coast. When the high nutrient laden water reaches the euphotic zone, the water becomes turbid from extensive plankton blooms. Change in distribution of turbidity provides another means of establishing the vertical and horizontal circulation.

The advection of deeper water shoreward and upward over the continental shelf produces a virtually isothermal layer at the bottom. It becomes progressively thicker as the upwelling develops, attaining a thickness of about 50 feet in March. This near bottom mixing is produced by convection currents set up when the denser water is introduced at levels above the bottom and by turbulence caused by frictional flow over the bottom.

At the termination of the southwest winds in the fall, a relaxing current is generated, and upwelling ceases. With the onset of the northeast monsoon, nearshore sinking develops. It, too, is demonstrable by the physical and chemical distributions in the water, and is explained by the dynamic processes existing in the eastern Bay of Bengal.

[1] These observations were made by the author while at the Andhra University, Waltair, India, as Visiting Professor of Oceanography on a Fulbright Grant in 1952 - 53 and 1955 - 56. Analysis and preparation of this paper were completed upon his return to the U.S. Navy Electronics Laboratory, San Diego, California.

Symposium: *Marine Upwelling—Biological Aspects*

THERMOCLINE TOPOGRAPHY, ZOOPLANKTON STANDING CROP AND MECHANISMS OF FERTILIZATION IN THE EASTERN TROPICAL PACIFIC†

WILHELM BRANDHORST‡

Inter-American Tropical Tuna Commission, La Jolla, California, U.S.A.

(Abstract)

The most important factor influencing fish aggregation in tropical waters is the food supply, based originally on the production of phytoplankton. Since there is a strong thermocline throughout the year and no seasonal "turn over" in the tropics, the availability of nutrients to the plants is dependent largely upon thermocline depth. A fall chart of the thermocline topography, based on *BT* observations, is compared with those showing zooplankton distribution and the abundance of tunas. The charts illustrate the interrelationship between thermocline depth, zooplankton standing crop, and abundance of tunas. Additional fertilizing mechanisms in certain areas of high productivity are described and explained by means of cross sections and charts showing surface distributions of temperature, inorganic phosphate, dynamic height, and current.

DISCUSSION

R.W. HIATT: Are there plans for C^{14} work in this area?

T. CROMWELL: Yes, a paper has been published on such work already; its title is "Primary Production, Chlorophyll, and Zooplankton Volumes in the Eastern Tropical Pacific Ocean," by Robert Holmes, *et al.* of Scripps Institution of Oceanography.

G.E.R. DEACON: Is there any hope of getting a more continuous picture of the amount of organic production like that of temperature given by *BT*'s? Are continuous transparency meters, or light scattering meters, fitted below the ship's keel likely to be generally useful?

T. CROMWELL: I think so, but an instrument sensitive for open ocean use has not yet been located by us.

J.H. RYTHER: Have any attempts been made to correlate the depth of the thermocline with the depth of the euphotic layer, and to relate these two factors together with the level of organic production?

T. CROMWELL: Not thoroughly as yet, but we plan to do so.

M.S. DOTY: High primary productivity and standing crops of chlorophyll have been found in the thermocline and deeper waters further west, and concern has been focused on the effects of the depth of the thermocline, therefore, in relation to the euphotic zone. This is considered to be very important.

R.W. HIATT: Is enrichment below the thermocline in shallow thermocline areas more important in the total amount of primary production than enrichment resulting from a depression of the thermocline as the surface water heats in domed areas?

T. CROMWELL: Results from C^{14} experiments in such areas off Costa Rica show the surface water to be more productive than water in and just below shallow thermoclines.

† Paper submitted for publication in the *Journal du Conseil Int. Explor. Mer.*

‡ Presented by T. Cromwell.

ENRICHMENT IN THE TRANSITION ZONE BETWEEN THE SUBARCTIC AND CENTRAL WATER MASSES OF THE CENTRAL NORTH PACIFIC

JAMES W. McGARY, EVERET C. JONES and JOSEPH J. GRAHAM

Pacific Oceanic Fishery Investigations, Honolulu, Hawaii.

The pattern of research of the Pacific Oceanic Fishery Investigations (POFI) of the U.S. Fish and Wildlife Service has been based on the hypothesis that, other things being favorable, concentrations of tuna are associated with the areas of highest productivity, and that these areas are characterized by modifications of the vertical stability of the two-layer system so that nutrient-rich water receives sufficient solar energy to produce a high rate of organic growth *(7)*. In 1954, POFI vessels began a series of cruises into the area between the Hawaiian Islands and the Aleutian Chain between 170°E. and 140°W. longitude to determine the oceanographic features which might point to regions of highest productivity and fishing potential. Concurrently, data on plankton, forage fish, and albacore tuna abundance were collected and attempts to relate these to the physical features of the water were made. The purpose of this report is to indicate in general terms, based on data collected during three years (1954 - 1956), the regions and probable mechanisms of enrichment in the central North Pacific.

Previous work in the central North Pacific has defined a number of water masses and associated features *(9)*. These include the eastern and western Central Water Masses, the Subarctic Water, and the North Pacific Current. Any attempt to subdivide these main categories or to define precisely their perimeters encounters difficulties because of inconsistent nomenclature employed by past investigators and the fundamental fact that precise boundaries between water masses or currents seldom, if ever, exist. A major obstacle in defining the water masses of the central North Pacific has been the paucity of winter observations. Before Cruise 25 of the POFI research vessel *Hugh M. Smith* in January-March, 1954 *(6)*, virtually nothing was known of the winter distribution of physical properties in that area *(2)*. In order to discuss water masses and their bearing on productivity, it is necessary to describe these masses in terms of temperature, salinity, or density and to set arbitrary limits where no real boundaries exist. In the present report Subarctic Water will be defined as having a salinity minimum at the surface. Central Water (eastern and western combined) will be defined as having a surface salinity of $35°/_{oo}$ or greater. The Transition Zone (North Pacific Current) (Fig. 1.) will be defined as having a subsurface salinity minimum and a surface salinity of less than $35°/_{oo}$. These divisions are not entirely arbitrary, as will be shown in the discussion of the temperature-salinity characteristics. Sverdrup *et al. (9)* do not define these water masses in terms of surface characteristics, but because this report is dealing with surface enrichment and productivity, which is a function of the euphotic zone, the present definitions become desirable.

The so-called North Pacific Current lies between the Subarctic and the Central Water Masses. Because it has temperature-salinity characteristics intermediate between these two, it will be called the "Transition Zone." This term is chosen in preference to the word "current" because the latter would seem to imply a very definite body of water with a single origin and direction of flow. The term "Polar Front" has been applied *(6)* to a zone of abrupt surface temperature changes located in winter at about 35°N. This term has since been applied to the transition between the Aleutian Current and the North Pacific Current, and in various unpublished reports it has been used to describe a "transition zone" which moves latitudinally from about 35° N. in winter to 46°N. in summer. The present authors prefer to avoid the term "Polar Front" because it implies a single abrupt change from Subarctic Water to water of the Central Water Mass, whereas oceanographic data now indicate a series of changes between the Central Water Mass and the Subarctic Water. Furthermore, the zone of most abrupt changes in surface temperature located in winter at about 35°N. is not comparable in origin or structure to the similar zone located farther north during the spring and summer. For these reasons, the term "transition zone" will be used in this report. These terms and arbitrary definitions follow closely those used by Hida *(4)* in describing three faunal zones in the central North Pacific, although he used the term "Subtropic Zone" rather than Central Water Mass to denote water with surface salinity greater than $35°/_{oo}$.

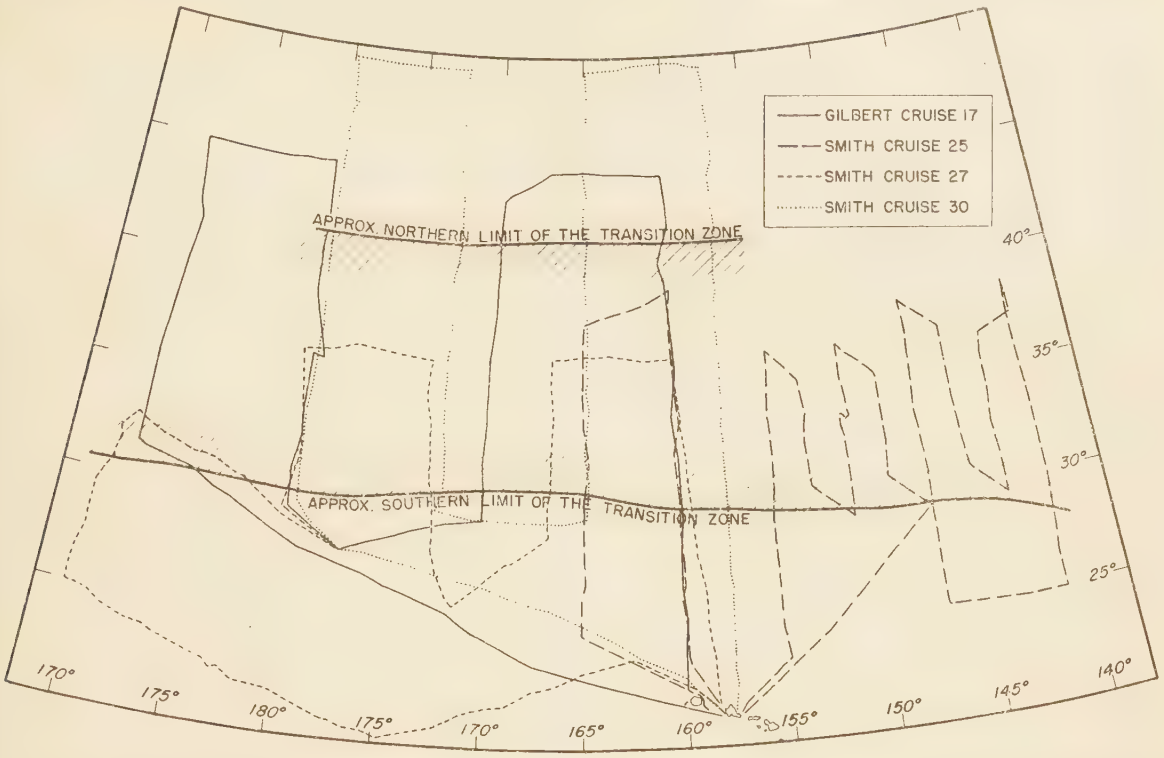


Fig. 1.—Tracks of four POFI oceanographic cruises to the central North Pacific between January, 1954 and August, 1955. Hatched area indicates the approximate limits of the Transition Zone.

The following discussion of enrichment patterns will stress those within the Transition Zone, although the zone of highest zooplankton production moves into Subarctic Water in summer. In the discussion of the oceanographic characteristics of the area, the transects made along 160° W. longitude or nearby will be used as examples because that longitude was surveyed more frequently than others and because conditions there seem to represent a mean between sharper zonation to the west and less well defined features to the east.

The temperature-salinity curves (Fig. 2) from POFI winter and summer cruises in the vicinity of 160° W. show seasonal changes in the relation of those two characters. Those from *Hugh M. Smith* Cruise 25, made during January, 1954, *(6)*, show an abrupt shift in T-S characteristics of the surface waters between Station 23 at 31° 09′ N. and Station 22 at 32° 50′ N. (our arbitrary division at the $35^{\circ}/_{\circ\circ}$ surface isopleth falls just south of Station 23 at 31° N.). A series of shifts continues to the north and corresponds to zones of relatively large geostrophic currents. Unfortunately this cruise did not extend far enough north to define the northern limits of the Transition Zone. T-S curves from *Hugh M. Smith* Cruise 30, made during August, 1955, *(5, 4)*, show two regions of abrupt shift in the surface portions of the curves. The most abrupt shift occurred between Stations 103 and 102 at 34°28′N. Farther north another rather abrupt shift was observed between Stations 94 and 93 at about 42° 30′N. North of that latitude the shifts in T-S characteristics became large between stations but with no distinct break indicating a major change in water source. Stations 93 and those north of it showed the salinity minimum at the surface, which follows our definition of Subarctic Water. The points of division on this transect agree with the faunal divisions as defined by Hida *(4)*.

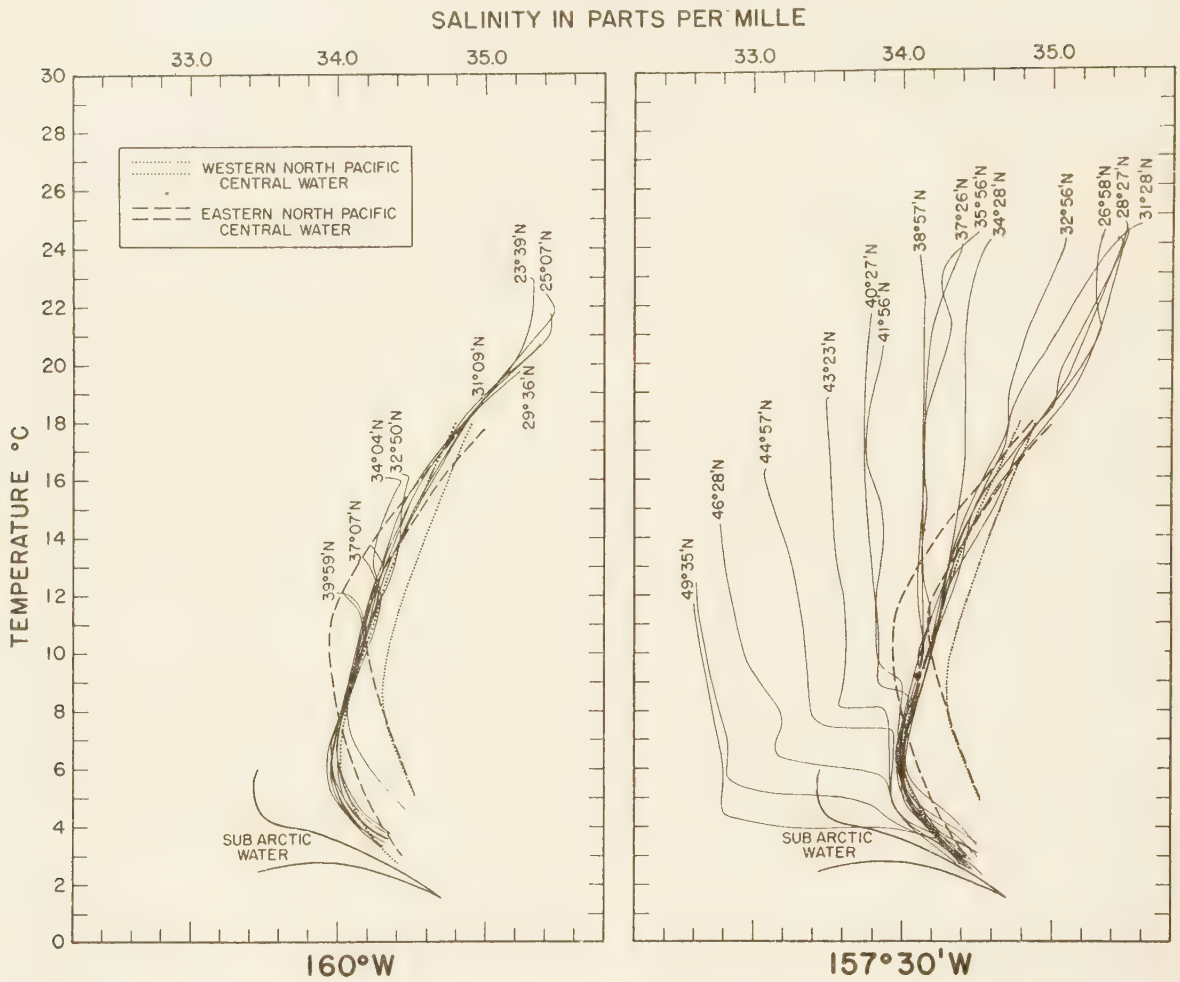


Fig. 2.—Left panel: superimposed temperature-salinity curves for the meridional station series along 160° W. longitude. *Hugh M. Smith* Cruise 25, January, 1954.
Right panel: same along 157°W. longitude, *Hugh M. Smith* Cruise 30, August, 1955.

Based upon T-S characteristics found on single winter and summer transects, the southern boundary of the Transition Zone occurred between 31°N. and 32°N. in winter and between 33°N. and 34°N. in summer. The variation in latitude of the 35°/$_{oo}$ surface isopleth among all transects of *Hugh M. Smith* Cruise 30, in summer, was from about 32°N. to about 34°N. The same variation among comparable transects of *Hugh M. Smith* Cruise 25, in winter, was from about 29° 30'N. to about 31°N. Considering the fact that the use of the 35°/$_{oo}$ surface isopleth as a dividing line is quite arbitrary, there is only slight evidence that the southern boundary of the Transition Zone occurs farther south in winter than in summer, and the seasonal shift amounts to no more than one or two degrees of latitude.

Surface and vertical temperature distributions typical of the Transition Zone and illustrating its latitudinal extent are shown in Fig. 3. The contrast between the summer and winter temperatures profiles (Fig. 3) shows the effects of seasonal heating and cooling in the surface layers. During both cruises the subsurface isotherms of 60° F. ascended sharply near the southern limit of the Transition Zone. In winter the northern limit of this ascent marked the beginning of the zone with little or no distinct surface layer; in summer it marked the beginning of a very shallow surface

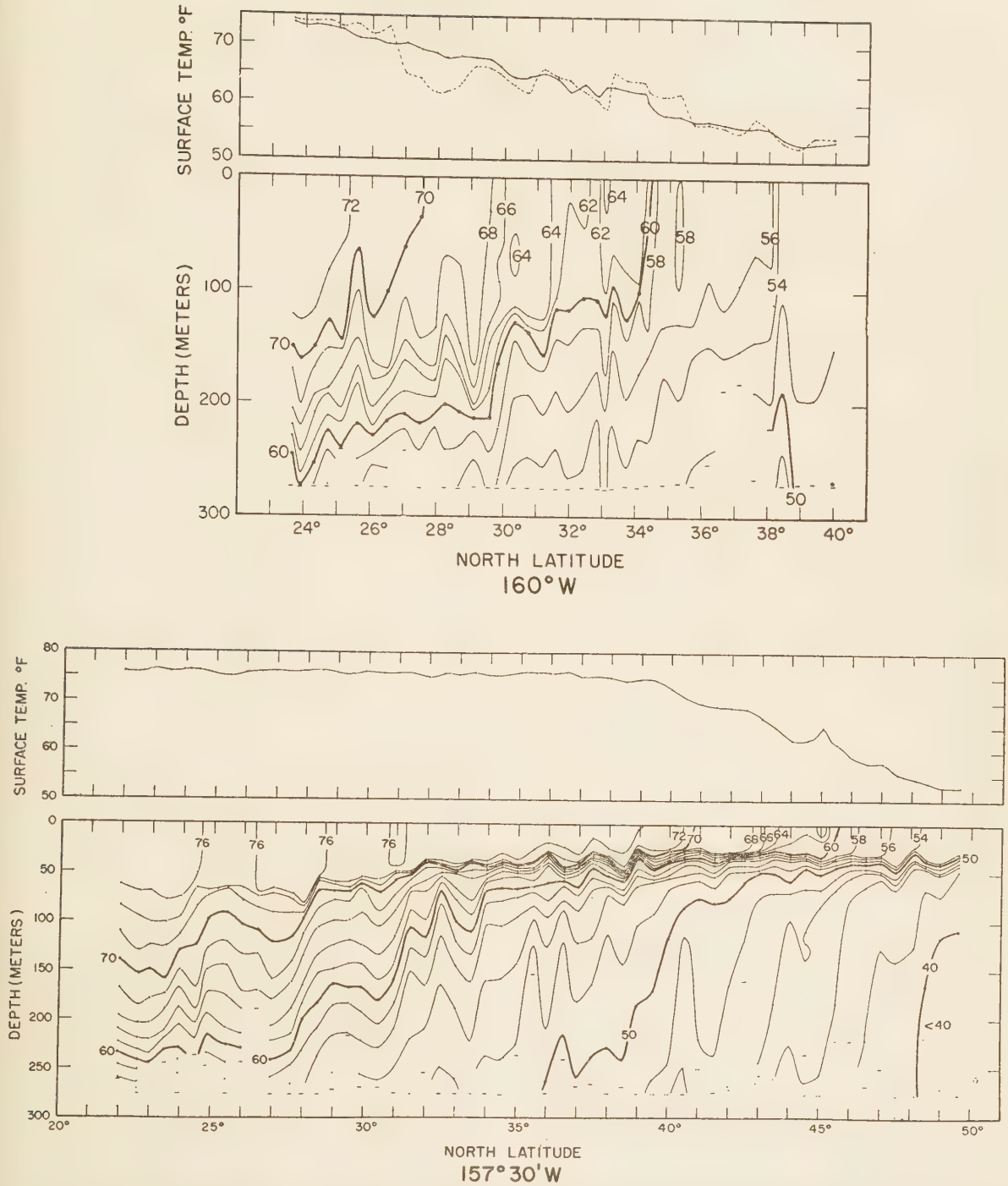


Fig. 3.—Upper panel: temperature section from *BT* casts along 160° W. longitude *Hugh M. Smith* Cruise 25, January, 1954. Lower panel: same along 157° 30° W. longitude, *Hugh M. Smith* Cruise 30, August, 1955. (Dotted line in surface temperature plot of the upper panel indicates air temperature.)

layer with an extremely sharp thermocline. The winter surface temperature profile shows a gradual decrease beginning well below the southern limit of the Transition Zone, with the largest horizontal gradient occurring within the Transition Zone between 64° and 58° F. surface isotherms. In mid-summer the surface temperature (Fig. 3) was almost uniform, 74° - 76° F., in the Transition Zone south of 39°N. latitude. From that point northward it dropped rapidly, with relatively large horizontal gradients occurring both in the Transition Zone (68° - 64° F.) and in the southern extremity of the Subarctic Water (62° - 58° F.)

Inspection of the data from other transects and cruises *(8, 3)* shows that in the central and eastern Pacific the greatest horizontal gradients and variation in surface temperature usually occurred within the 56° to 68° F. range during all seasons of the year. These relatively great horizontal temperature gradients were also associated with the formation and breakup of the shallow, stable surface layer and are probably the feature that has given rise to the term "Polar Front." This would account for the large seasonal latitudinal variation often attributed to the "Front."

Such complexities in T-S characteristics and temperature structure of the surface layers are not surprising when it is remembered that the Transition Zone corresponds to the northern limit of the warm layer of the oceans to which Defant *(1)* has applied the name "troposphere," a term borrowed from meteorology. This northern limit is subject to numerous modifying processes resulting from annual variations in heating and cooling and from fluctuations in the ocean currents. It is an area of convergences in winter between the cold Subarctic Water and the Central Water Mass. By virtue of being between the warm and cold water masses, it is the zone where greatest heat exchange takes place in the surface waters. Furthermore, it is in the latitudes where the annual heat budget of the world as a whole indicates a boundary between a net loss and a net gain of radiant heat and a maximum in poleward atmospheric heat transport *(9)*. Because of these circumstances, it is the zone of greatest annual fluctuations of sea surface temperature. The Transition Zone is also subject to large annual variations in wind direction because of the seasonal changes in the position and intensity of the eastern North Pacific High and the Aleutian Low. All of these features tend to impede the formation of a stable two-layer system, and this lack of stability results in enrichment of the euphotic zone.

Enrichment occurs in the Transition Zone through the mixing of two bodies of water with different physical and chemical properties (*9*, p. 795) which stimulates the growth of phytoplankton. In this instance water of intermediate temperature and nutrient content is formed in winter from the admixture of warm, nutrient-poor Central Water and cold but relatively rich Subarctic Water. The inorganic phosphate content of the surface waters during *Hugh M. Smith* Cruise 25, in midwinter, showed the largest horizontal gradient corresponding to the most abrupt changes in T-S characteristics (Fig. 2). Further examination of the data, however, showed that admixture alone could not account for the increases in phosphates. Water to the east of 160°W. at the same temperature apparently contained a greater percentage of water of northern origin but had a lower phosphate content. Examination of the physical data from this cruise indicated that the horizontal gradients in geostrophic currents in the western part of the cruise area (160°W. and 165°W.) were greater than in the eastern part (141°W.). This would indicate that vertical mixing as a result of turbulence in the areas of relatively large current shear to the west of 160°W. contributed to the enrichment of the surface waters in the Transition Zone. No well defined zone of greatest zooplankton abundance was encountered on this winter cruise, but the highest volumes (in cc. per 1,000 cubic meters of water strained) were at 36° N. and 37° N., or just north of the most abrupt changes in surface temperature (Fig. 4) in an area presumably affected by vertical turbulence. South of 35°N., within the Transition Zone or in Central Water, there is no evidence of enrichment reflected in zooplankton volumes or evidence of any mechanism to produce such enrichment.

In addition to the enrichment processes associated with turbulence in the atmosphere and the ocean is the effect of winter overturn. In winter the Transition Zone and waters to the north of it are subjected to vertical mixing induced by heat lost to the atmosphere. This overturn is also accelerated by the high wind velocities associated with winter storms. In spring, surface warming causes a marked thermocline to develop, beginning about 35° N. and extending northward as the season progresses until by late summer (August and September) it reaches to 47° N. or 48° N. The frontier of this warming layer apparently offers optimum conditions for a phytoplankton

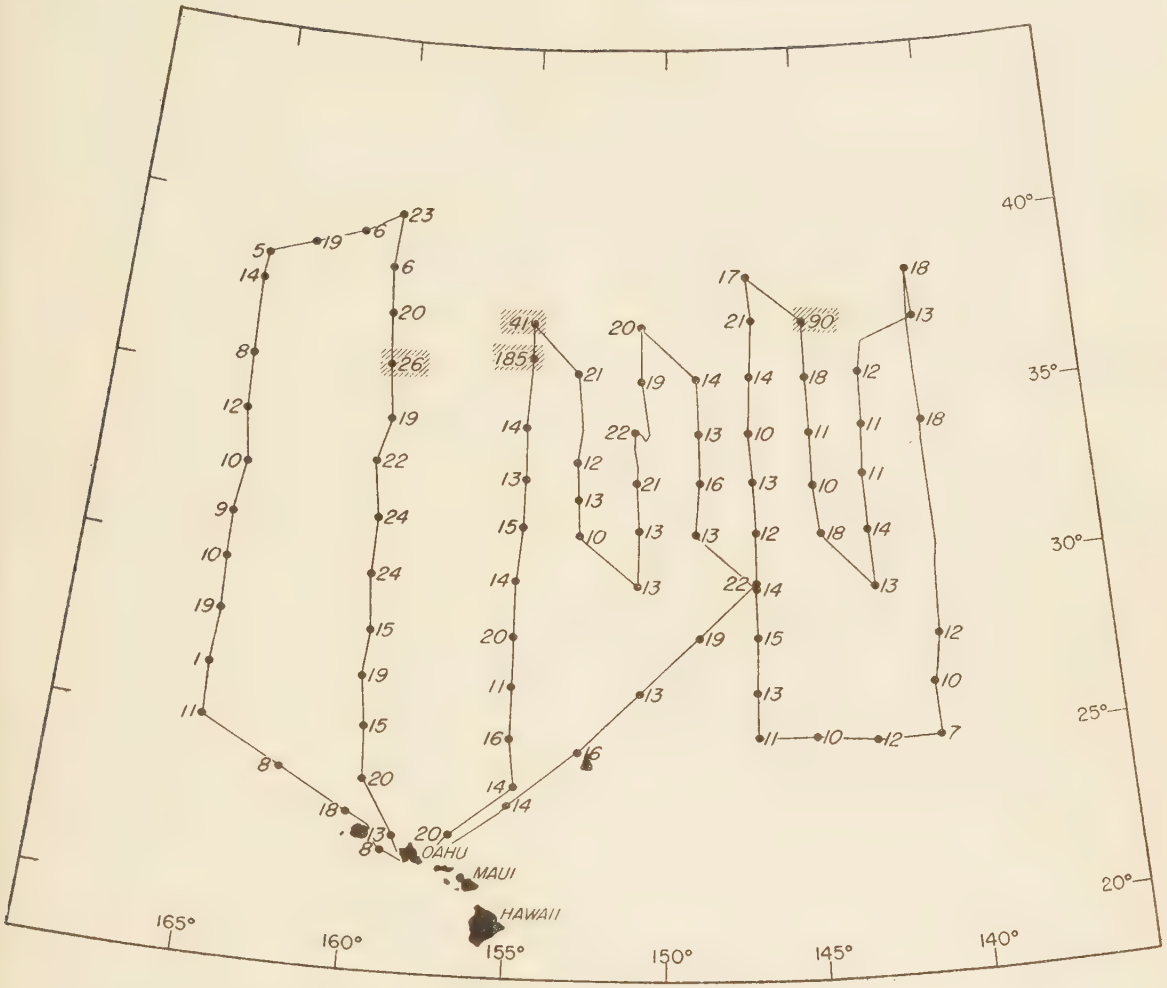


Fig. 4.—Zooplankton volumes in cc/1000 m.³ from a winter cruise, *Hugh M. Smith* Cruise 25, January - March, 1954. Values over 25 are shaded.

bloom followed by an increase in zooplankton abundance. Isotherms of 56° to 60° F. (identical with temperatures in the zone of abrupt change in winter) shift northward, but salinity data indicate that this is not a shift in the current directions. Further evidence that this is not a shift in currents is found in the composition of the zooplankton. Tropical copepods are limited to water of 58° F. or warmer, but in summer, when the warm surface layer forms, it is not occupied by tropical species but by eurythermal forms such as *Calanus helgolandicus*, *C. tonsus*, or the nauplii of the pelagic barnacle, *Lepasfascicularis*. In August, 1955 (*Hugh M. Smith* Cruise 30) a tongue of high zooplankton abundance composed principally of *Calanus* was encountered from 40° N. to 50° N. South of this the volumes of zooplankton dropped sharply until a distinct zone of less than 10 cc. per 1,000 m.³ was encountered just north of 35° N. (Fig. 5). This seemed to indicate that after the frontier of surface warming and high productivity had passed to the northward the upper layer no longer had the potential for producing a high zooplankton crop. While no data on surface phosphates are available from that cruise, another summer cruise, *Charles H. Gilbert* Cruise 17, produced evidence that the plankton minimum was associated with a surface phos-

phate minimum. These zones of plankton maxima and minima are not continuous bands across the central North Pacific, but appear to occur in irregular pulses which indicate a complexity of water origin and mixture beyond complete analysis with present information. The mechanism of winter overturn and surface warming in spring appears to result in high zooplankton abundance within the Transition Zone in early summer and in Subarctic Water in late summer.

In winter the Transition Zone appears to be an area of convergences marked by a series of rather abrupt changes in T-S characteristics and surface temperature. The principal mechanism of enrichment appears to be turbulence and admixture between waters of dissimilar chemical and physical properties. In summer there is no evidence of convergence and the principal mechanism for enrichment appears to be surface warming following winter overturn. There is no evidence of upwelling at any season.

The complex physical and biological attributes of the Transition Zone are difficult to relate in detail to the distribution and abundance of albacore tuna, *Germo alalunga* Bonnaterre, which in man's interest represents the end product of enrichment and productivity. There are certain features of the environment and of the distribution and abundance of albacore which are highly coincident, however. During the winter months the albacore are found near the southern boundary of the Transition Zone at 28° to 32° N. latitude. In the spring a segment of these fish, composed of the smaller members (<90 cm.), may be found at the surface, where they appear to follow northward the latitudinal shifts of surface isotherms of 55° to 65° F. This range includes the largest horizontal gradients within the Transition Zone. The albacore stay within this range as it moves northward, presumably following the plankton bloom and the large populations of forage organisms associated with the zone of

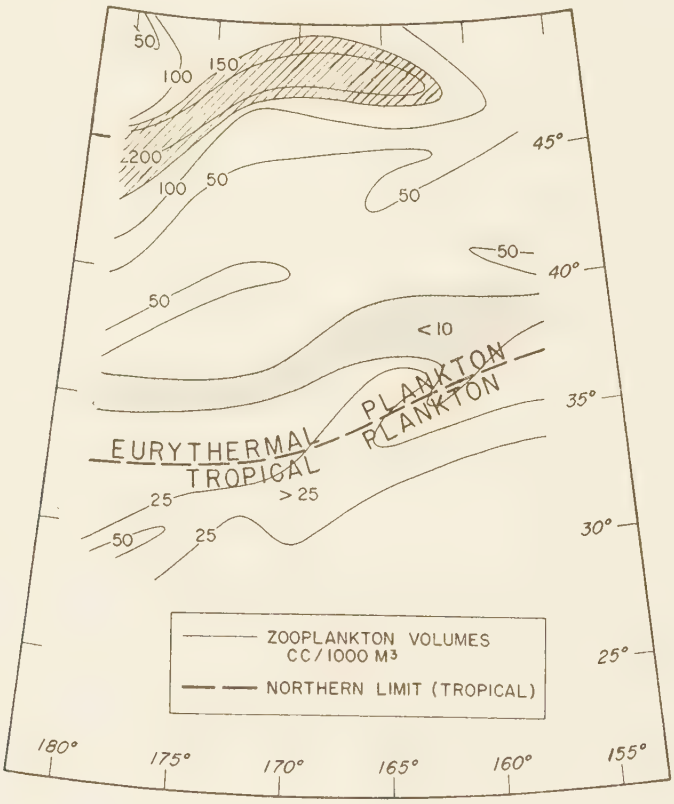


Fig. 5.—Zooplankton volumes in cc/1000 m.3 from a summer cruise, *Hugh M. Smith* Cruise 30, July-August, 1955.

highest productivity. In mid-and late summer this zone and the associated albacore have reached Subarctic Water. As Hida *(4)* has pointed out, the distribution of albacore does not appear to be associated with the types of water but rather with certain temperatures which may well be coincident with favorable feeding conditions. With the advent of approaching winter, the albacore which have been residing near the surface appear to descend to considerable depths and move generally southward along with the retreating isotherms of 55° to 65° F.

REFERENCES

(1) Defant, A., 1928, *Die systematisch Erforschung des Weltmeeres.* Gesellsch. f. Erdkunde, Zeitschrift, Jubilaums Sonderband. Berlin. p. 459 - 505.

(2) Fleming, R.H., 1955, Review of the Oceanography of the Northern Pacific, *U. of Wash. Dept. of Oceanography, Tech. Rept.*, **44**: 1 - 43.

(3) Graham, J. J., 1957, Central North Pacific Albacore Surveys, May to November 1955, *U.S. Fish and Wildlife Serv., Spec., Sci. Rept.* (*Fish.*), **212**: 1 - 38.

(4) Hida, T.S., 1957, Chaetognaths and Pterodpods as Biological Indicators in the North Pacific, *U.S. Fish and Wildlife Serv., Spec. Sci. Rept.* (*Fish.*), **215**: 1 - 13.

(5) McGary, J.W., Jones, E.C. and Austin, T.S., 1956, Mid - Pacific Oceanography IX: Operation NORPAC, *U.S. Fish and Wildlife Serv., Spec. Sci. Rept.* (*Fish.*), **168**: 1 - 127.

(6) McGary, J.W., and Stroup, E.D., 1956, Mid-Pacific Oceanography VIII: Middle Latitude Waters, January - March 1954, *U.S. Fish and Wildlife Service, Spec. Sci. Rept.* (*Fish.*), **180**: 1-173.

(7) Sette, O.E., 1955, Considerations of Mid-ocean Fish Production as Related to Oceanic Circulatory Systems, *J. Mar. Res.*, **14** (4): 398 - 414.

(8) Shomura, R. S. and Otsu, T., 1956, Central North Pacific Albacore Surveys, January 1954 - February 1955, *U.S. Fish and Wildlife Serv., Spec. Sci. Rept.* (*Fish.*), **173**: 1 - 29.

(9) Sverdrup, H.U., Johnson, M.W. and Fleming R.H., 1942, *The Oceans, Their Physics, Chemistry, and General Biology.* New York: Prentice-Hall, 1087 pp.

DISCUSSION

J.H. RYTHER: How long does the band of high productivity persist in any one given area?

A.L. TESTER: This may be estimated roughly, knowing that the band is at about 32° - 33° N. lat. in, say April and at about 47° - 48° N. lat. in September.

Y. HIYAMA: The fishing records from Japanese albacore boats show a movement of albacore northward which coincides very well with the wave of plankton abundance described in this paper. It is very likely that these two waves are correlated, and hitherto we have not known why the albacore fishery moves northward as the season progresses.

F. NEAVE: Have surveys extended north of the wave of plankton, or did your survey stop at what is shown as the northern boundary of the wave?

A.L. TESTER: Yes, they extended northward beyond the boundary of the wave.

M.S. DOTY: How wide is the wave?

Y. HIYAMA: About 5° - 10° wide.

A.C. HARDY: It would be interesting to work out trophic succession. What are the tuna feeding on?

A.L. TESTER: Saurep and squid.

J.H. RYTHER: This demonstrates nicely the suggestion of Sverdrup as regards the control of spring diatom growth.

CLIMATIC RECORDS ON THE OCEAN FLOOR†

GUSTAF O. S. ARRHENIUS‡

Scripps Institution of Oceanography, La Jolla, California, U.S.A.

DISCUSSION

Y. MIYAKE: Is the temperature shown on the curves for $CaCo_3$ production the surface temperature?

R. REVELLE: Probably not; probably below the thermocline.

T. CROMWELL: At what depths do foraminiferans live at present? Does the method of temperature determination by isotopes of oxygen lead to an integrated temperature value, i.e., integrated over the depths occupied by living foraminiferans?

R. REVELLE: It depends on the number of individual foraminiferans and the analysis. The O^{16}/O^{18} method requires only a small amount of material, but I don't know how much was actually used.

† Submitted for publication to the Rossby Memorial Volume.

‡ Presented by Dr. R. Revelle.

ENRICHMENT PATTERNS RESULTING FROM EDDY SYSTEMS†

MICHITAKA UDA

Tokyo University of Fisheries, Tokyo, Japan.

The undulated patterns of oceanic fronts due to shearing instability caused by the velocity difference on both sides of fronts develop as eddies. On the line of convergence designated by current-rips and slicks on the sea surface, we find the sinking of watermasses and accumulation of dusts, drifting substances, and some living organisms including planktons, fishes, whales, etc., which commonly show some biological line of demarkation.

The line of divergence along the coastal region of continents or islands or near the oceanic banks caused by the prevailing offshore current or offshore wind and sometimes by the collision of undercurrent onto a bank or shelf, corresponds to the zone of upwelling representing the area of rich nutrient salts and consequently plenty of marine life. This has been found by the Meteor Survey (A. Defant) and recently by the California Cooperative Oceanic Fishery Investigations (1950-56).

The fine structure of oceanic front has been developed by many authors: M. Uda (1938), T. Cromwell and Joe Reed (1956) of SIO, mainly on the fronts along the Equatorial Countercurrent, and by many oceanographers of Woods Hole, e.g., C' O.D. Iselin, Worthington, Fuglister, La Fond, H. Stommel, Haurwitz, Panovsky, Von Arx, etc., on the edge of the Gulf Stream with the adjacent cold belt and warm core, meander and the shingle structure of the Gulf Stream.

The structure of Oyashio Front and Kuroshio Front was developed recently by many Japanese oceanographers, e.g., H. Jawai, J. Masuzawa, T. Ichie, D. Shoji, M. Koizumi, S. Hikosaka, etc.; and some of them discussed the eddy development by applying the theory of perturbation theoretically.

In the following, the author classifies the enrichment patterns resulting from eddy systems into three types.

(1) Dynamical Eddy Systems

The collision of two different current-systems, e.g., cold and warm current or the currents belonging to the oceanic water and coastal water, develop dynamic oceanic fronts which migrate to and fro as the strength of the current on each side varies.

For example, if we compare the isotherms in the upper layer (at the depths of 10, 50, and 100 m.) of the North Pacific Ocean obtained by the Norpac Project in the summer of 1955, and the location of the fishing grounds of important pelagic fishes (skipjack, albacore, bluefin-tuna, salmon, squid, Pacific saury, and whales) in the same summer season, we can show that the most favorable fishing ground—or in other words, the most productive zones — almost coincide with the eddies associated with oceanic frontal zones. In particular, the cold patches at the center of the cyclonic eddy lying near the southernmost tip of the cold current corresponds to the most concentrated localities of Pacific saury, whales (fin whale, sperm whale, etc.), and albacore in spring and early summer (M. Uda).

On the contrary, the warm core showing anticyclonic eddy (especially of pocket-in type of warm watermass) lying near the top of the warm current corresponds to the dense fishing localities of skipjack, sei-whale, and albacore in the midsummer.

It appears that the migrating fishes stay in the eddies and run quickly between the eddies, intermingling and interchanging of fish-shoals in the consecutive eddies according to its sequence.

The dynamical eddies along the Polar Front, including both Oyashio Front and Kuroshio Front, show the cold occluded or warm occluded front type as the north-going (from early spring to midsummer) or south-going (from late summer to winter) shift of the general pattern in accompaniment with the fluctuation of cold and warm currents, and also in addition to them the stationary front as the intermediate type from mid- to late summer.

The summer profiles of water temperature in the Northwestern Pacific obtained by the Norpac Project indicate clearly the coupling of the cold (upwelling) and warm (sinking) watermasses at those eddies on the front and the most favorable fishing grounds in relation to them. The location

† Presented by Prof. Koji Hidaka.

of cold and warm occluded watermasses of the above eddies to the important fishing grounds and therefore to the enrichment patterns show some quasi-stationary distribution and consequently fluctuate around the average month by month or year by year. The degree of enrichment seems to be proportional to the amount of vorticity of each eddy and generally to the convergency of the Polar Front, roughly to the temperature gradient of the watermasses on both sides of the front.

(2) The Topographical (or Orographic) Eddy System

We have already studied the eddy systems caused by the irregularities of topography (elevation, depression, configuration, size and depth of islands, banks, straits, bays, etc.) which represent the local fishing grounds associated with those eddies. In order to discover the mechanism of those local enrichment patterns produced by the peculiar topographical features, the author studied with Mr. M. Ishino by means of model experiments in the water tank at the Tateyama Laboratory belonging to the Tokyo University of Fisheries during the period 1952 - 54.

Although the experimental results on eddies are shown qualitatively by many photographs and sketches, we can note the stream-lines disturbed by the islands or banks corresponding to the direction of the main stream-axis and the eddies behind the islands, also to the peculiar traces of the bottom sand which indicate the upwelling zone denoting the area of comparatively similar size to that island and having the local front fringing it.

Actually we made several surveys of Kuroshio in the adjacent waters of Hachijo Island and local eddies produced by islands and banks in the area on board of *Umitaka Maru*, *Shunkotsu Maru*, and *Shinyo Maru* (1952 - 55).

The fishing grounds of some important commercial fishes (e.g., flying fish, skipjack, and mackerels) appear to be located on such topographically stationary eddy systems. These migrate successively from one eddy system to another formed by islands or submarine banks.

(3) The Combined Type, Partly Topographical and Partly Dynamical Eddy System

The following are examples of this type studied by us.

In Japan Sea. The conspicuously meandering front of Tusima Current since the year 1941, represents several cyclonic eddies corresponding to the top of the encroaching cold current which dominates on some configuration of deep-sea floor and several anticyclonic eddies of warm watermass on the shallow elevation.

Those eddies appear as topographically quasi-stationary, but more or less variable. Along the frontal edge of the Tusima Current, the migration route of the pelagic fishes are generally found. Also, the boundaries of several cyclonic eddies coincide remarkably with some enrichment patterns (fertilized cold water area due to upwelling) and are important as the fishing grounds of sardine, mackerel, etc.

In the East China Sea. Some complex structure of frontal zone near the shelf edge of the East China Sea at the depths of 50-200 m. between the Coastal Shelf Water and the Offshore Water of Kuroshio System. Commonly the shelf margin is occupied by the relatively turbid, plankton rich water, showing higher productivity due to the upwelling of the intermediate slope water mingled with the cascaded water from the bottom layer of the Yellow Sea (similar to that of Celtic Sea discussed by L. Cooper), and the encroachment of this cold water onto the warm Kuroshio water at the head of sea valleys on the continental shelf edge.

Eddies of Subtropical Convergency near Ogasawara Island. These were observed by the author (M. Uda, 1955) and correspond to the favorable whaling grounds and tuna fishing grounds (M. Uda 1937, 1952).

Eddies around the East Sakhalin Cold Current. These eddies are north of Hokkaido and correspond to the favorable whaling ground (M. Uda, 1954).

Eddies on the Continental shelves of the South China Sea and East China Sea in Relation to the Trawl Fishing Grounds (M. Uda, 1941).

CONCLUDING REMARKS

Emphasis is given here to the importance of the enrichment patterns resulting from eddy systems. Their relationship to the commercial fishing grounds for exploitation and conservation is noted. The concentrated areas of food animals including nekton, plankton, and benthic fauna are fertilized by upwelling and accumulated or hydrobiologically limited by convergence. The dynamically-conditioned eddy systems are subjected to the fluctuation of the currents of watermasses. On the other hand, the topographically-conditioned eddy systems are subjected to the

local topographic features including bottom configuration. In general, the enrichment of those eddies is affected deeply by the dominant upwelling of the deep water; in particular, by the cyclonic eddies in the Northern Hemisphere and by the prevalence of cold current associated with oceanic climate.

The most enriched season seems to occur just in the period succeeding the convection or turnover period, turbulent mixing period by currents, waves, and swell, etc. In the future we should study the hydrobiological mechanism and the dynamics of eddy systems in more detail quantitatively.

PRIMARY PRODUCTIVITY PATTERNS IN ENRICHED AREAS†

MAXWELL S. DOTY and MIKIHIKO OGURI

Department of Botany, University of Hawaii, Honolulu 14, Hawaii.

The variations in oceanic productivity can be thought of as due largely to the interactions of four major factors: phytoplankton, sunlight, inorganic fertilizers, and grazing organisms. The ways these factors are brought together result in primary production, the intensity of which is a function of the changing concentrations of these factors and the inherent abilities of the phytoplankters to produce and reproduce.

While related *(4, 7)*, one must distinguish productivity from standing crop. Productivity is thought of as the actual or potential rate of production. Productivity is generally expressed in terms of mass of material or calories of energy transferred through the particular step under consideration per unit of time per unit of area or volume. Comparable standing crop measurements lack the time element of the productivity measurements. In our primary productivity work the measurements are expressed as the mass of inorganic carbon converted to organic carbon by photosynthesis per unit or time per unit of volume. *A priori* there is little reason why there should exist any particular correlation between productivity and standing crop measurements.

In the ocean, fertilizers are brought into the oceanic euphotic zone from terrestrial, aerial,[1] and dysphotic regions: (a) in transition or shear zones enriched by vertical mixing or eddies, (b) in divergent current areas by upwelling, (c) in wind disturbed areas by the vertical mixing, e.g., in wind cells, and (d) near land by fertilizer increases arising both through concentration by benthic organisms and through addition by freshwater.

The carbon-fourteen technique of determining the primary production rate *(2)* has been applied to the determination of productivity variations in all four such areas. The results are often striking.

As one enters the north subarctic transition zone *(6)* from the south, an increase of about threefold in productivity is found *(3)* (Fig. 1). This appears to be an area enriched by vertical mixing during winter periods, but was formerly considered to be a zone with mixing related to local eddy systems. Sorokin *(8)* reports an even larger similar increase further west. Fig. 1 presents productivity and standing crop data collected during a winter cruise of the U.S. Fish and Wildlife Service vessel, *Charles H. Gilbert*, near 160° W. longitude. It may be seen from this figure that the magnitude of standing crops of zooplankton and phosphate phosphorous is not necessarily directly related to magnitude of productivity, although both may vary in the same direction.

Vertical mixing areas, such as provided by wind cells, can be expected to yield local concentrations, or patches, in which the productivity is significantly greater than that perhaps a hundred meters away. Fig. 2 graphically shows the results obtained from four separate series of samplings across such local areas.

As one approaches land *(1)*, there can be expected to appear in the phytoplankton population, aside from the benthic population, an increase in productivity of at least two orders of magnitude.

When crossing a region of equatorial upwelling, an increase often of nearly one order of magnitude *(5)* can be expected. Fig. 3 reproduced here with the kind permission of the Pacific Oceanic Fishery Investigations of the U.S. Fish and Wildlife Service, shows the productivity of an area of equatorial upwelling in the eastern tropical Pacific. Such has been found correlated with higher concentrations of inorganic fertilizer salts *(5)*; and King *(4)* as well as Murphy and Shomura *(7)*, present figures which provide a picture of the relationships between inorganic physical productivity and certain standing crop factors in the sea.

† This technique was developed with financial assistance provided on contract AT (04-3)-15 with the U.S. Atomic Energy Commission and by funds from the Graduate Research Committee of the University of Hawaii, and on the cruises of Pacific Oceanic Fishery Investigations vessels of the U.S. Fish and Wildlife Service.

[1] Elements added from the air, e.g., nitrogen, are unknown insofar as variations in their rates of addition at sea are concerned.

Contribution No. 104 of the Hawaii Marine Laboratory.

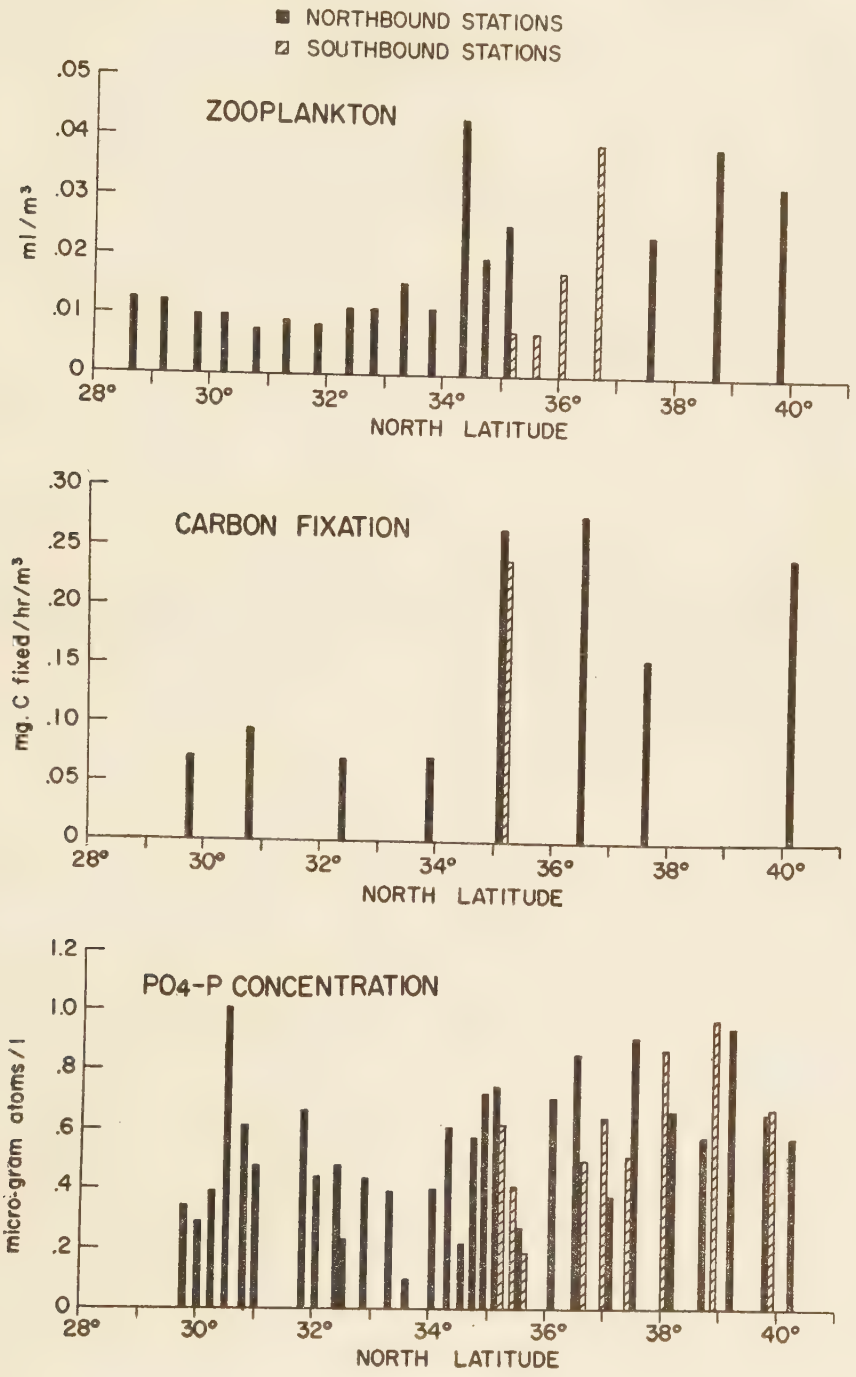


Fig. 1.—Data from Cruise 18 of the U.S. Fish and Wildlife Service vessel, *Charles H. Gilbert*. Productivity and standing crop are plotted as a function of the latitude in the vicinity of 160° W. longitude.

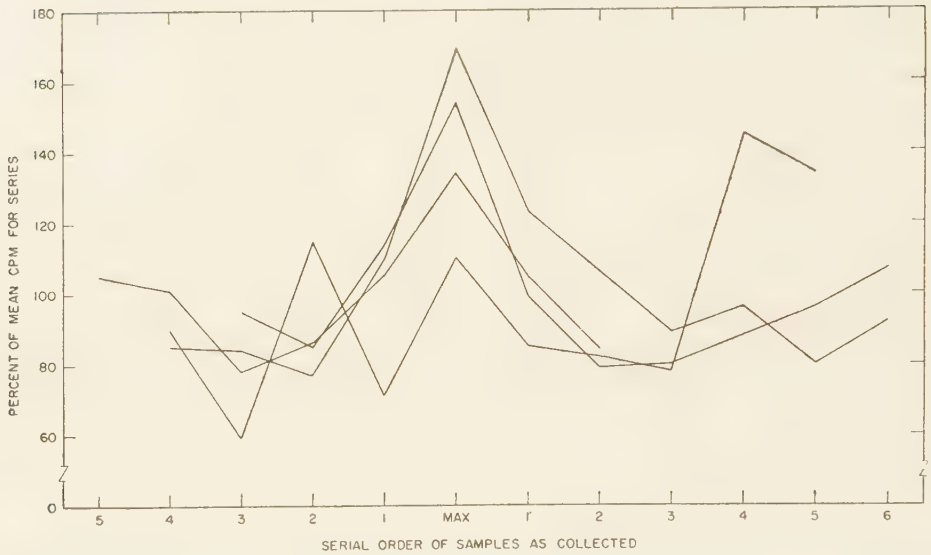


Fig. 2.—C^{14} technique measurements in per cent of the mean value for the series is plotted as a function of the serial order of the sample away from the maximum values which are plotted at the same position on the chart for all series. It is assumed that the values increased as the samples were taken from the sea surface while the vessel drifted slowly through a patch of plankton concentrated by such an agent as water movements in a wind cell.

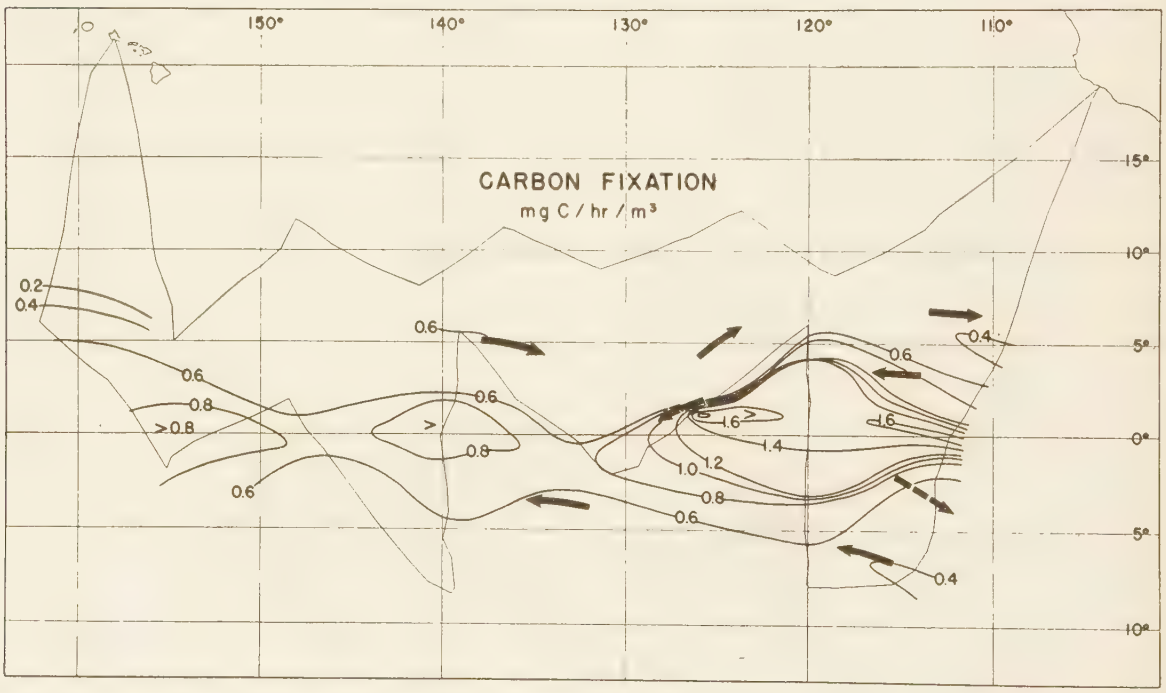


Fig. 3.—Horizontal plot of surface productivity as determined by the C^{14} technique on Crusie 31 of the U.S. Fish and Wildlife Service vessel, *Hugh M. Smith*. The arrows indicate geostrophic currents and are the same as those presented in similar figures in the paper in this symposium by King.

REFERENCES

(1) Doty, M.S., Oguri, M., 1956, The Island Mass Effect, *Journal du Conseil Int. Explor. Mer*, **22**(1): 33-37.

(2) ————, (In press), Selected Features of the Isotopic Carbon Primary Productivity Technique, *Rapp. et Proc. Verb. Cons. Int. Explor. Mer*, **144**: 51-59.

(3) Guillard, R.R.L., Doty, M.S. and Oguri, M., 1955, The Productivity of Waters North of Hawaii as Determined by C^{14} Uptake, Abstract from the *Proc. Hawaiian Acad. Sci.* **1955 - 1956**: 10.

(4) King, Joseph E., 1958, Variation in Abundance of Zooplankton and Forage Organisms in the Central Pacific in Respect to the Equatorial Upwelling, *Proc. Ninth Pac. Sci. Congr.* **16**: 98.

(5) ————, Austin, T.S., and Doty, M.S., 1957, Preliminary Report on Expedition EASTROPIC, *U.S. Fish and Wildlife Serv. Spec. Sci. Rept.* (*Fish.*), **201**: 155 pp.

(6) McGary, James W., Jones, Everet C. and Graham, Joseph J., 1958, Enrichment in the Transition Zone between the Subarctic Water and Central Water Masses of the Central North Pacific, *Proc. Ninth Pac. Sci. Congr.*, **16**: 82.

(7) Murphy, Garth I. and Shomura, Richard S., 1958, Variation in Yellowfin Abundance in the Central Pacific, *Proc. Ninth Pac. Sci. Congr.*, **16**: 108.

(8) Sorokin, J.I., 1957, The Results of Using Radioactive C^{14} for a Study of Organic Matter Cycle in Water Basins, *UNESCO International Conference on Radioisotopes in Scientific Research*, paper 140, 16 pp.

DISCUSSION

J.C. MARR: Is the high peak of production in the wind cells always at their center?

M.S. DOTY: We are not certain.

A.C. HARDY: Was the distance between the patches of phytoplankton production uniform?

M.S. DOTY: This is usually true, but no observations of possible related wind cells were made at the time these particular data were obtained.

T. CROMWELL: We have found no change in quantity of primary productivity approaching islands. Have you ever obtained similar results?

M.S. DOTY: Yes, particularly when very small islands were concerned, but when all such data from our approaches to islands are considered, a reliable increase towards shore seems apparent.

A.C. HARDY: Are the patches circular or in bands?

M.S. DOTY: We assume that they are linear. The results were obtained in experiments designed for other purposes, and the interpretation of the results as due to wind cells is quite hypothetical. No data were obtained which permit a better answer than this.

J.H. RYTHER: In your work near Oahu in the Hawaiian Islands, what is the depth of the thermocline layer?

M.S. DOTY: It is usually below the lowest levels sampled.

J.H. RYTHER: Do you get an actual enrichment as Oahu is approached? How deep is wind mixing?

M.S. DOTY: There is an increase in total phosphorus, as implied from consistent standing crop measurements, but no great increase in inorganic phosphorus has been found as the shore is approached. Wind mixing seemed to extend to the bottom in shallow water near shore and below the 1 per cent light level, at about 100 meters, offshore.

H.S. SWINGLE: Why should you use the productivity of organic carbon, rather than nitrogen, for example?

M.S. DOTY: Because primary productivity of organic carbon can be measured easily and more reliably than is true for measuring any other index of primary productivity.

M.S. Doty also commented on the diurnal rhythm in photosynthetic rate under constant light conditions. He found this rhythm progressively reduced from lower to higher latitudes, related presumably to sharpness of diurnal rhythm.

J.H. Ryther described a recent experiment in which the photosynthetic rate was related to the previous exposure to light or darkness.

VARIATION IN ABUNDANCE OF ZOOPLANKTON AND FORAGE ORGANISMS IN THE CENTRAL PACIFIC IN RESPECT TO THE EQUATORIAL UPWELLING

JOSEPH E. KING

Pacific Oceanic Fishery Investigations, U.S. Fish and Wildlife Service, Honolulu, Hawaii.

During the past eight years the Pacific Oceanic Fishery Investigations (POFI) of the U.S. Fish and Wildlife Service has conducted intensive studies of the oceanography and relative productivity of the tropical Pacific. The underlying premise in this research program has been the hypothesis that the greatest biological productivity, as evidenced by the standing crops of zooplankton, forage organisms, and tuna, is most likely to occur in areas of vertical instability where there is chemical enrichment of the euphotic zone *(9)*.

The high degree of thermal stratification and vertical stability that exists throughout much of the tropical central Pacific is interrupted at the Equator by the equatorial divergence with resultant upwelling of nutrient-rich water, as first demonstrated by the *Carnegie* section of 1929 *(11)* and confirmed by the researches of this organization *(1, 4)*. The divergence in the surface waters is caused by a combination of two factors: (1) the Coriolis Force of the Earth's rotation, and (2) the tradewinds blowing steadily from the east or southeast for the greater part of the year.

There are other mechanisms operating in the tropical Pacific which may cause apparent enrichment. These occur in areas of shallow thermocline near the northern boundary of the Countercurrent and in the eastern Pacific *(2, 5)* where high phosphate water is brought within the photosynthetic zone and within the reach of wind-induced turbulence. Also, the convergence commonly occurring between the Equator and the southern boundary of the Countercurrent may theoretically have a concentrating effect on plankton and thus increase the feeding efficiency of forage organisms. In this brief report we shall consider mainly the effects of the equatorial upwelling.

THE EASTROPIC EXPEDITION

During the months of September - December, 1955, five agencies[1] joined forces to study the physical, chemical, and biological oceanography of the central and eastern Pacific. As POFI's participation in this, the EASTROPIC expedition, the *Hugh M. Smith* obtained information on east-west gradients in temperature, salinity, phosphate, zooplankton, and forage fish abundance along the northern boundary of the Countercurrent and along the Equator between 110° W. and 156° W. longitude *(7)*. The track of the cruise is shown in Fig. 1.

The results of the Eastropic expedition demonstrate how variations in abundance of zooplankton and forage organisms are related to the equatorial divergence and upwelling. Also, information was obtained which is of some aid in evaluating the "lag" periods or trophic succession, in the development of zooplankton and forage fish populations in the newly enriched, surface water of the equatorial region.

MAJOR FEATURES OF THE ENVIRONMENT

The general circulation features calculated from hydrostatic considerations are illustrated in Fig. 2 for that portion of the area in which deep-station data were obtained on the dynamic topography.[2] The easterly flowing Countercurrent is shown at 5° N. latitude, with an unusual southerly inflection at 132° W. longitude. To the south of the Countercurrent is the westward-flowing South Equatorial Current.

The more significant features revealed by the surface temperature observations (Fig. 3) were the comparatively slight variation with longitude in the Countercurrent, the southerly inflection

[1] Scripps Institution of Oceanography, Inter-American Tropical Tuna Commission, California Department of Fish and Game, the Peruvian Navy, and the U.S. Fish and Wildlife Service.

[2] The Eastropic oceanographic data were processed under the supervision of T.S. Austin, Oceanographer, POFI, and we are indebted to Mr. Austin for the interpretations of these data given in this report.

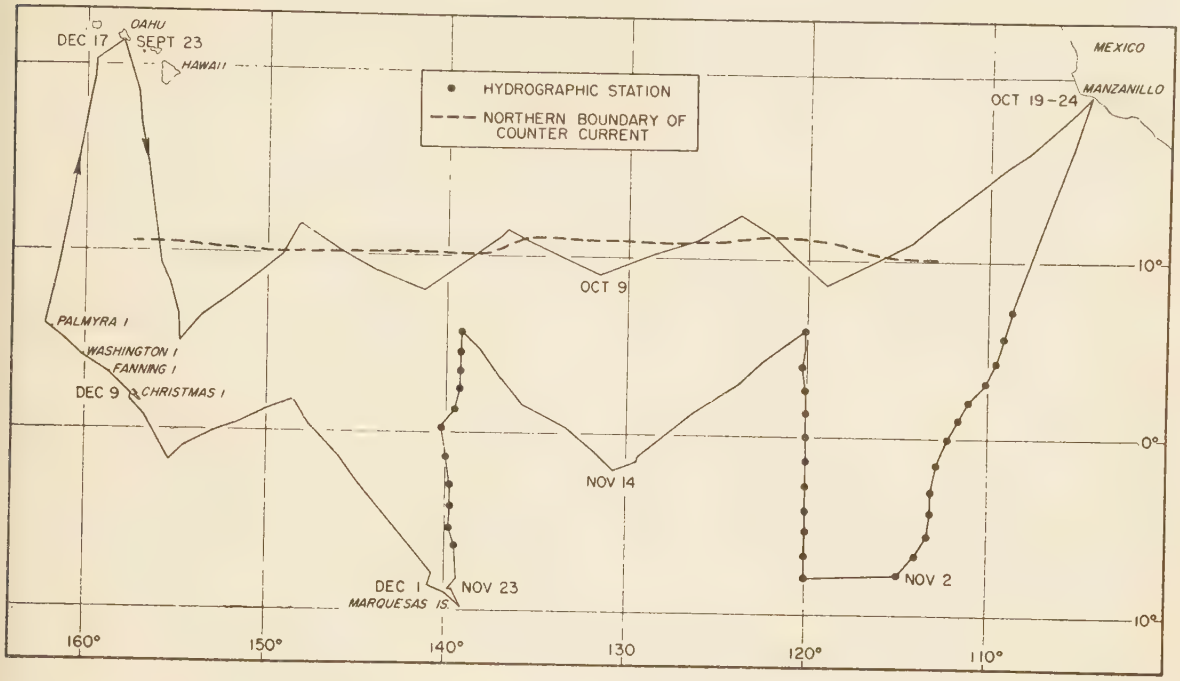


Fig. 1.—Track of the *Hugh M. Smith* on the Eastropic expedition, September 23 to December 17, 1955.

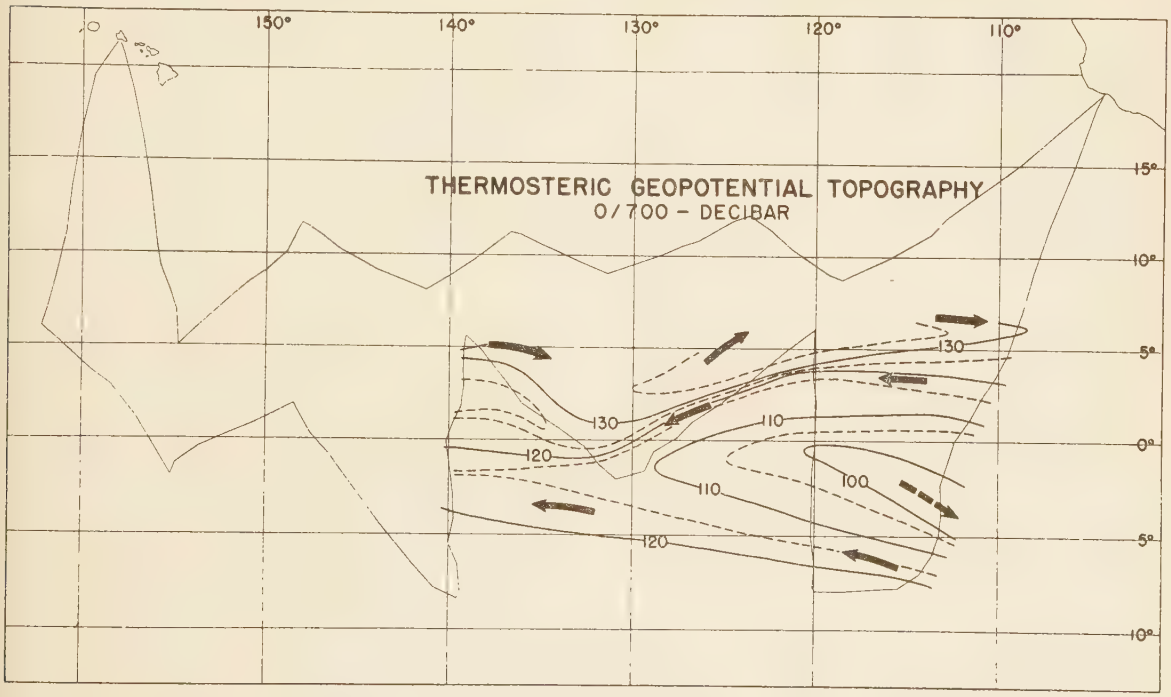


Fig. 2.—Surface currents observed on the Eastropic expedition.

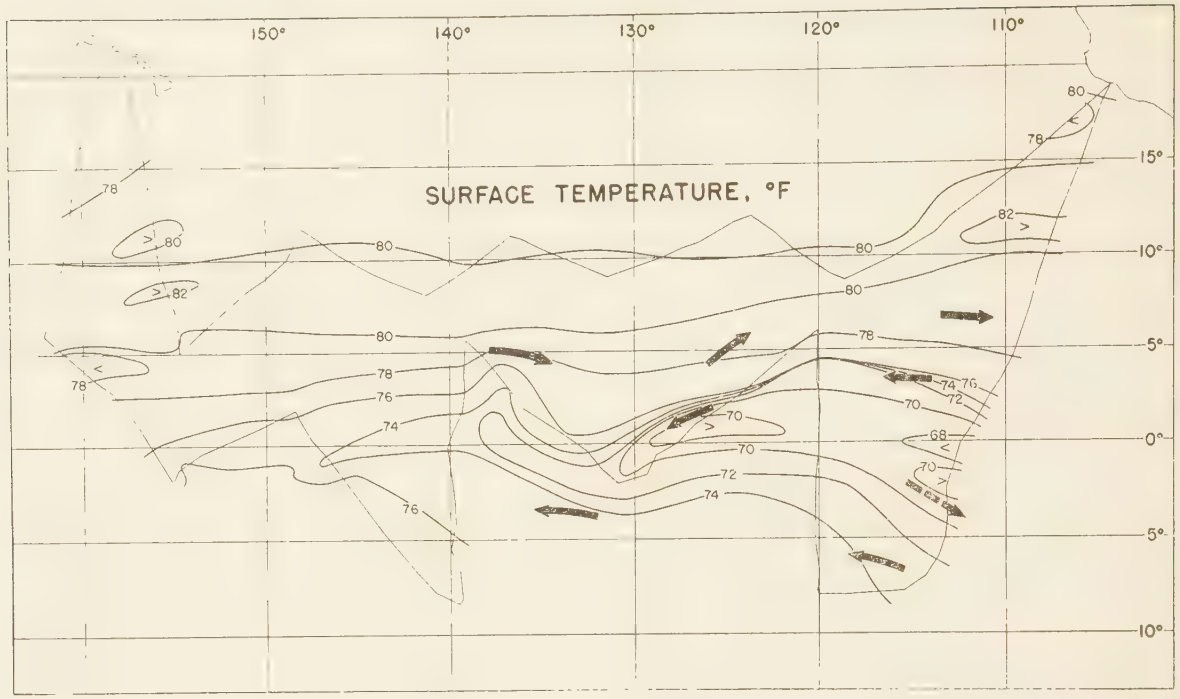


Fig. 3.—Variations in surface temperature observed on the Eastropic expedition.

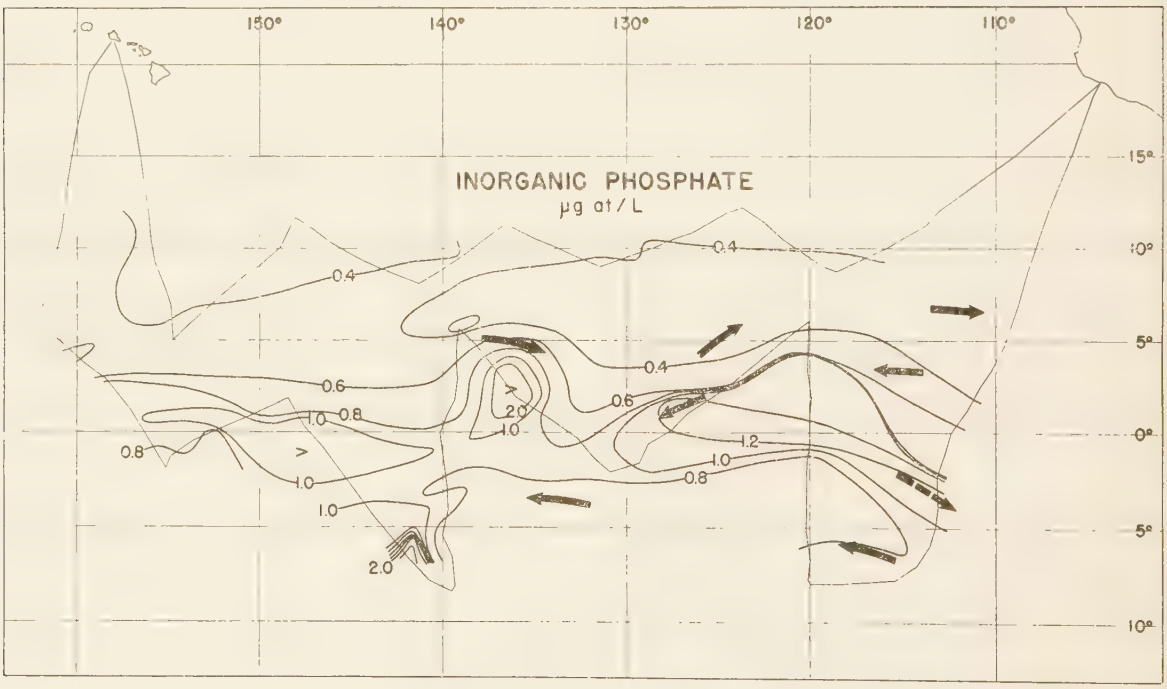


Fig. 4.—Variations in surface inorganic phosphate as determined on the Eastropic expedition.

in the isotherms at about 132° W., the closely packed isotherms between 125° W. and 118° W. associated with a "front" in the surface currents, and the comparatively cold water on the surface along the Equator.

Three significant characteristics of the inorganic phosphate distribution (Fig. 4) are worthy of mention: the sudden change in phosphate across the front, the comparatively low values of phosphate in the old water of the Countercurrent, and the comparatively high values in the newly upwelled water along the Equator.

ZOOPLANKTON

Methods

By means of closing-net hauls, a special study was made on Eastropic of the vertical distribution of zooplankton *(7)*. Two plankton stations were occupied each day, one between 0900 and 1100 and the other between 2100 and 2300 hours (ZT). All hauls were made with 1-meter (mouth diameter) nets of 30×××silk grit gauze (apertures 0.65 mm.). The amount of water strained on each haul was measured by a flowmeter suspended in the mouth of the net. The sampling depth was measured on a number of hauls with a depth gauge of the Bourdon type.

Four types of hauls were employed: (1) closing-net oblique hauls with 3 nets sampling simultaneously at 3 levels, at approximately 0-52 m., 66-134 m., and 147-272 m.; (2) open-net oblique hauls to about 231 m.; (3) closing-net hauls sampling obliquely between average depths of 227 and 369 m.; and (4) a short series of 20-minute surface hauls taken in conjunction with the front and not discussed in this report.

Variations with Time and Depth

The marked decrease in zooplankton abundance with depth and the diurnal variation in the catch are shown in Fig. 5. The night/day ratio was 1.72 for the 0-52 m. hauls, 1.05 for the 66-134 m. hauls, 0.89 for the 147-272 m. hauls, and 1.51 for the 0-231 m. hauls. The 227-369 m. hauls, which were all made during the day, averaged slightly higher in volume than the 147-272 m. hauls. These results would seem to indicate that the major part of the increase at night in the shallow hauls was due to less successful dodging on the part of the plankton or was derived from zooplankton that migrated from depths below those sampled.

A high positive correlation was found between the 0-52 m. samples and the 0-231 m. samples; for the day hauls, $r = 0.599$ ($P < 0.01$); for the night hauls, $r = 0.742$ ($P < 0.01$), with 48 degrees of freedom in each instance. These two sampling methods, therefore, yielded the same general picture of plankton variation.

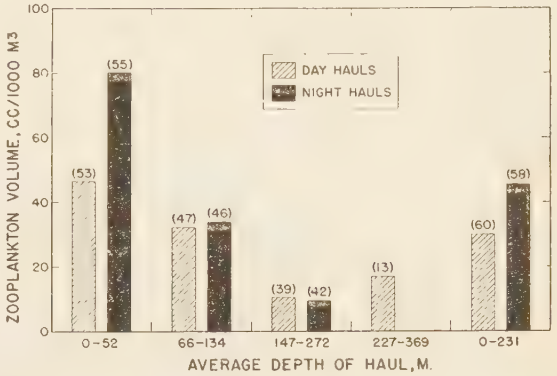


Fig. 5.—Variation in zooplankton volume with depth and time of hauling, as obtained on the Eastropic expedition. Number of samples is shown in parentheses.

Horizontal Variations

In the night hauls (Fig. 6), the highest volumes were obtained in the equatorial divergent and convergent zones between 115° W. and 135° W. longitude. In the equatorial region, there was a marked decrease in abundance to the west of 135° W. longitude. The several high volumes secured along the northern boundary of the Countercurrent are indication that some enrichment was occurring in this area. A generally similar picture of zooplankton distribution was provided by the day hauls, which are not illustrated. The effects of enrichment were not as marked, however, as in the samples taken at night.

In view of the slight day-night difference at the levels fished by the intermediate and deep nets, the catches at those levels were plotted in Fig. 7 irrespective of time of hauling. In general, the highest volumes obtained with the intermediate net were also taken near the Equator and near the northern boundary of the Countercurrent. On 120° W. and 140° W. longitude, greater-than-average volumes were taken south of the Equator. With the deep net, the highest catches were made south of the Equator. Further study is required, however, before the full significance of these results can be properly interpreted.

The few samples derived from the closing net operating at 227-369 m. showed considerable geographic variation. One larger-than-average sample was obtained near the northern boundary of the Countercurrent, and there were two large samples from near the Equator. The remainder were generally low in volume.

FORAGE ORGANISMS

On the Eastropic cruise a 1-hour haul was made each night, usually between 2000 and 2100 hours, with an Isaacs-Kidd trawl *(6)* equipped with a nylon net of 1-1/2 inch mesh (stretched measure) in the wings and body, and with finer

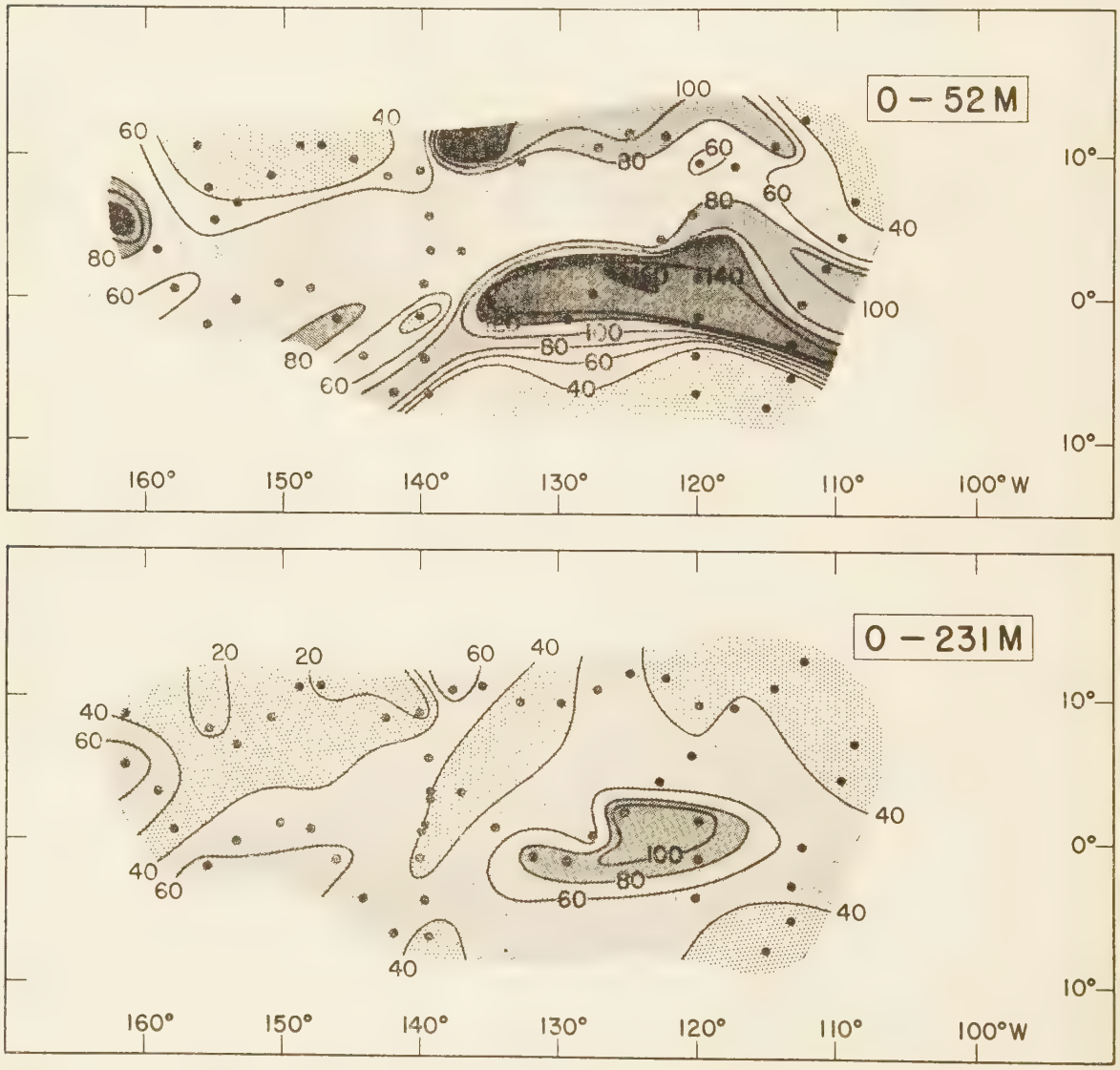


Fig. 6.—Horizontal variation in zooplankton abundance (cc/1000 m³) as measured in night hauls at 0-52 m. (upper panel) and at 0-231 m. (lower panel) on the Eastropic expedition.

mesh in the rear section and cod end. The trawl, fishing between the surface and about 350 m. depth, captured a wide variety of bathypelagic fish, shrimp, euphausiids, and other invertebrates.

The largest catches were obtained near the Equator at 146° W. to 150° W. longitude, and, in general, the best catches were made near but usually to the north of the Equator (Fig. 8). Near 140° W. longitude good catches were made in the Countercurrent. Thus it would seem that the abundance of forage organisms sampled by the mid-water trawl was also influenced by the basic enrichment at the Equator, and possibly by that occurring in the region of the Countercurrent.

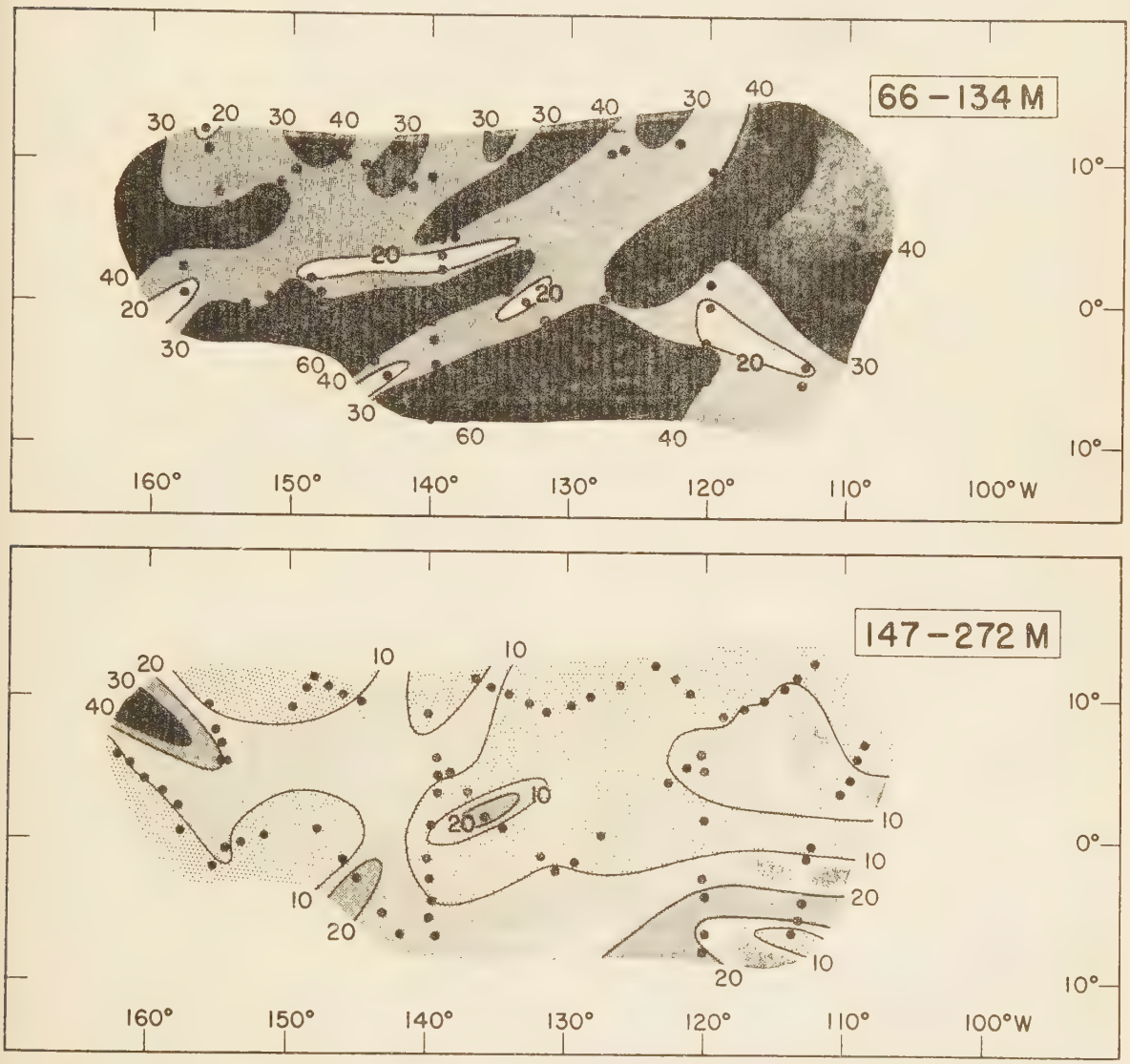


Fig. 7.—Horizontal variations in zooplankton abundance (cc/1000 m³) as measured in day and night hauls with closing nets operating at 66-134 m. (upper panel) and at 147-272 m. (lower panel).

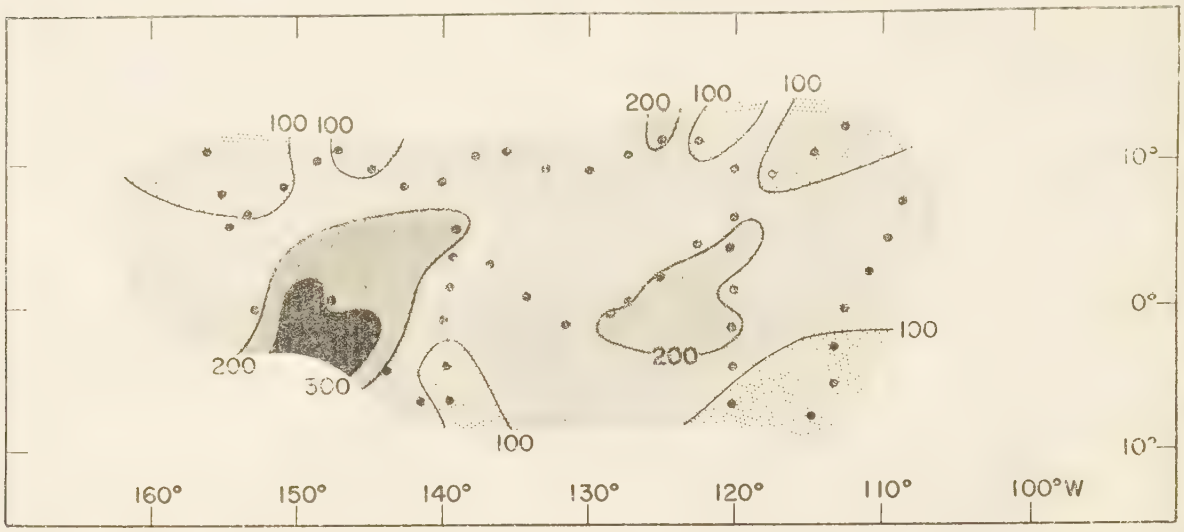


Fig. 8.—Horizontal variations in the volume (cc.) of catch obtained in 1-hour hauls with a 10-foot Isaacs-Kidd trawl, fishing to about 350 m. depth.

ECOLOGICAL AND TROPHIC RELATIONSHIPS

As previously described, the presence of the divergence and upwelling at the Equator is reflected in marked changes in several features of the environment. Fig. 9 shows the variations along 120° W. longitude, observed on the Eastropic expedition, in surface and subsurface temperature, density (thermosteric anomaly), inorganic phosphate, and dissolved oxygen, with associated variations in the abundance of zooplankton and forage organisms as shown in Fig. 10. The similar doming at the Equator and generally high degree of covariation in these different factors of the environment and of the biota is indeed striking and could certainly not occur by chance alone.

An exact description of the sequence of events following the entry of nutrient-rich water into the euphotic zone cannot yet be given for the tropical Pacific. Newly upwelled water is at first poorly populated as regards both phytoplankton and zooplankton *(10)*. From what is known of the growth of plankton populations in other parts of the world, we may postulate that a phytoplankton population should develop in the "new" water within a few days, a zooplankton population within less than a month, and a concentration of forage fishes after an unknown interval. This entire process should be greatly accelerated in the tropical Pacific because of favorable light and temperature and a continually renewed supply of nutrients.

The surface currents of the equatorial Pacific are a highly dynamic system. Within the westerly flowing South Equatorial Current, which straddles the Equator, there are northerly and southerly components resulting from the equatorial divergence *(4)*. As newly upwelled water flows to the westward, it also flows away from the Equator, and because the prevailing winds in the eastern and central equatorial Pacific are from the southeast, the major drift is usually to the north. In meridional transects, such as the one along 120° W. shown in Fig. 9, we should expect to find the age of the surface water to vary directly with latitude; i.e., within the limits of the equatorial current system the older water should occur at the higher latitudes. Once this system is established, therefore, we should find the peak zooplankton population slightly asymmetric in respect to the Equator and probably displaced to the north. Because of the time lag in their development, the forage organisms should be concentrated at an even greater distance from the Equator.

The results of the Eastropic expedition previde evidence which both contradicts and supports these hypotheses. In Fig. 10 we show the variation in abundance of zooplankton and forage organisms along the three, principal, north-south transects of Eastropic, which crossed the Equator on 112° W., 120° W. and

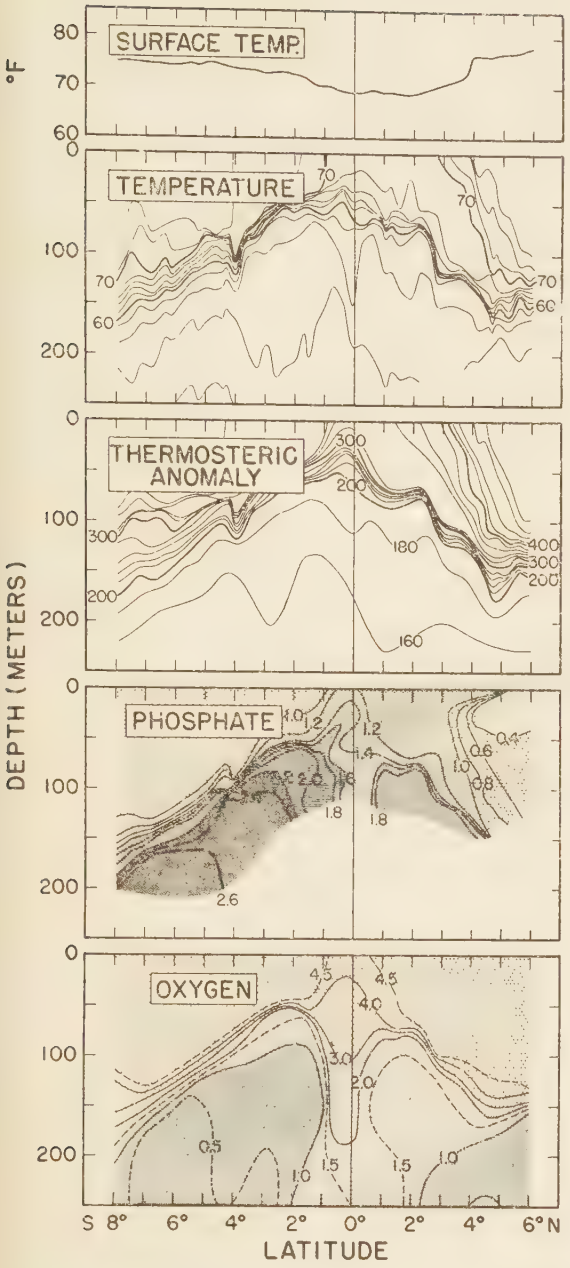


Fig. 9.—Variations with latitude along 120° W. longitude in surface temperature, subsurface temperature (°F.), density (thermosteric anomaly, cl/T.), inorganic phosphate (μg at/l.), and dissolved oxygen (ml/l.); *Hugh M. Smith* Cruise 31 (Eastropic), November 4-9, 1955.

140°W. longitude. This method of portrayal illustrates, perhaps more clearly than the contour charts of Figs. 6-8, the latitudinal variations along a single meridian in respect to the equatorial upwelling. From the location of the major peaks, or modes, on the abundance curves of Fig. 10, we constructed Fig. 11, which shows

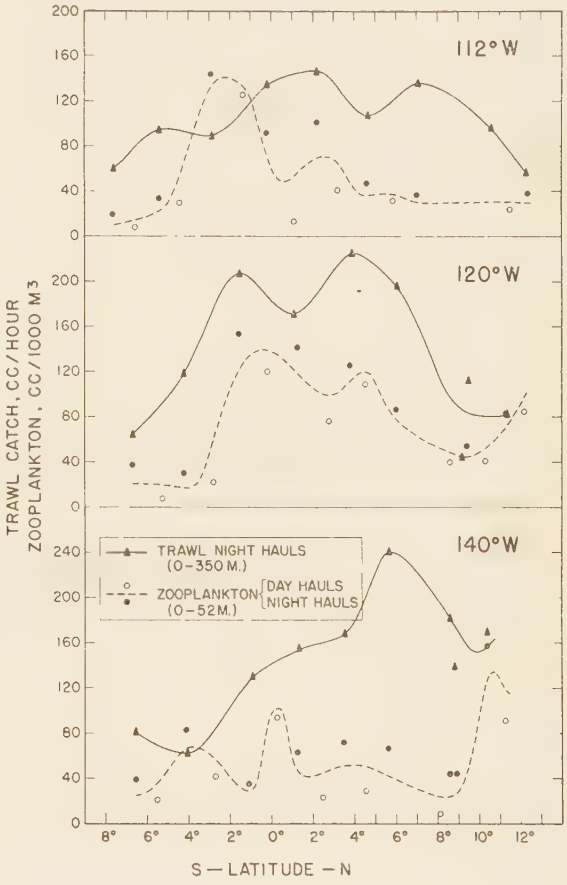


Fig. 10.—Variations with latitude in zooplankton volume (0-52 m. hauls) and trawl catch, on north-south transects crossing the Equator on 112° W., 120° W. and 140° W. longitude; *Hugh M. Smith* Cruise 31 (Eastropic), October-November, 1955.

diagrammatically the latitudinal variation with longitude in the peak catches of zooplankton and forage organisms. In both groups the peak shifts northward from east to west, but for reasons which we cannot explain, the zooplankton peak was considerably south of the Equator in the eastern part of the area. In Cromwell's *(4)* model of wind direction and current transport for the

equatorial Pacific, he indicates that under conditions of southeast winds the divergence may be centered between 1° S. and 2° S. latitude, whereas with an east wind the divergence is centered on the Equator. T. S. Austin *(3)*, in a summary of the wind observations on Eastropic, has shown that on both 110° W. and 120° W. during the period of the cruise, there were strong southeast winds between the Equator and 6° N., but more easterly winds south of the Equator. The wind conditions south of the Equator at the time of the cruise, therefore, do not aid in explaining the southerly displacement. The configuration of the isotherms on the 112° W. transect (7, p. 17) indicate that here the center of the upwelling was near 1° S. latitude rather than on the Equator. The distribution of inorganic phosphate and density also indicate that the major upwelling was occurring south of the Equator.

latitudes was approximately 9.3 and 7.5 times the velocity of the northerly or southerly component.

The pilot charts for October and November, 1955 (U.S. Navy H.O. Chart No. 1401) show an average westerly drift of about 1 knot in the region of the Equator. Other considerations based on geostrophic calculations *(3)* and on measurements with the geomagnetic electrokinetograph *(8)* have provided current estimates for the area ranging from 0.1 to 5 knots. If we accept the pilot chart average of 1 knot or 24 miles a day for the westerly drift, then the poleward displacement of the zooplankton peak from the Equator, which appears to be the approximate center of the upwelling as judged principally by the vertical temperature structure, is at the rate of 0.11 knot or 2.6 miles a day. The 30- to 90-mile interval between the site of upwelling and the zooplankton peak may thus represent 12 days

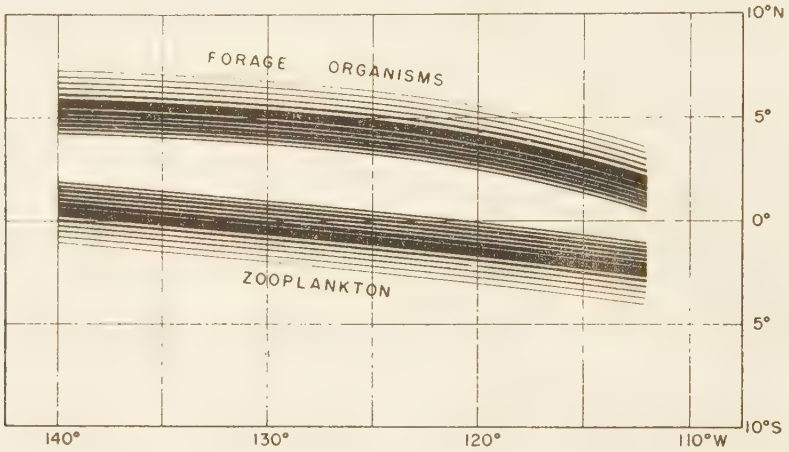


Fig. 11.—Geographical variations in the peak abundance of zooplankton and forage organisms, as found on *Hugh M. Smith* Cruise 31 (Eastropic), October 27 - December 6, 1955.

Because of the complexities in the surface currents it is extremely difficult to trace the biotic succession in space and time. Throughout the area sampled, the principal forage peak occurred about 5 degrees (300 miles) north of the zooplankton peak, and shifted from 2°N. latitude on 112°W. longitude to 5-3/4°N. latitude on 140°W. longitude (Figs. 10 and 11). The zooplankton peak shifted from 2-1/2° S. latitude at 112° W. longitude to 1/2°N. latitude at 140°W. longitude. This displacement, expressed as a ratio of longitude to latitude, equals 9.3 for zooplankton and 7.5. for forage organisms. We interpret these figures to mean that the westerly drift at these

at 140°W. and about 35 days at 112°W. There is some indication, however, that the currents were stronger in the east, as were the winds, so that this latter figure is probably too high.

Following this same manner of reasoning, the northerly displacement of the forage organisms, in respect to the zooplankton peak, is at the rate of 0.13 knots or 3.1 miles a day. The 300-mile interval between the peaks of the two trophic levels thus represents about 97 days in time. At 2 knots westerly drift the northerly component would be 6.2 miles a day and the time interval between trophic peaks about 48 days.

As the forage organisms are not "drifters" but are capable to a large degree of selecting their environment, one might assume that they would occur in greatest abundance in the zone of optimum feeding. Their food most likely consists of other nekton and the macroplankton. The fact that the two peaks in abundance do not coincide is dependent, we believe, on the greater time interval required for the populations of forage organisms to develop in the new water. While the rate of plankton production may also be high in the zone of abundant forage, the standing crop of plankton is greatly reduced by the intensive grazing.

We are aware of the over-simplification in the description above. In this highly dynamic ecosystem the interrelationships are bound to be extremely complex. To realize the final objectives of these studies, that is, to thoroughly understand and to predict the occurrence of commercially profitable tuna stocks, will require considerable more knowledge of the nature and rate of trophic succession as related to the ever changing environment.

BIBLIOGRAPHY

(1) Austin, T. S., n.d., *Review of Central Equatorial Pacific Oceanography*, 1950 - 52. Pacific Oceanic Fishery Investigations, (unpublished manuscript).

(2) _____ and Rinkel, M.O., 1958, Variations in Upwelling in the Equatorial Pacific, *Proc. Ninth Pac. Sci. Congr.*, **16:** 67.

(3) _____, n.d., *Oceanography of the East-Central Equatorial Pacific as Observed During Expedition EASTROPIC*, Pacific Oceanic Fishery Investigations, (unpublished manuscript).

(4) Cromwell, T., 1953, Circulation in Meridional Plane in the Central Equatorial Pacific, *Jour. Mar. Res.* **12** (2): 196-213.

(5) _____, 1956, EASTROPIC Expedition —What It Seeks and Where It Fits into Practical Industrial Fishing, *Pacific Fisherman*, **54** (8): 25, 27, 29.

(6) Devereaux, R.F. and Winsett, R.C., 1953, Isaacs - Kidd Midwater Trawl, Final Report, Scripps Institution of Oceanography, University of California, *SIO Reference*, **53** (3); *Oceanographic Equipment Report* **1**: 21 pp.

(7) King, J.E., Austin, T.S. and Doty, M.S., 1957, Preliminary report on expedition EASTROPIC. *U.S. Fish and Wildlife Serv. Spec. Sci. Rept.* (*Fish.*) **201:** 153 pp.

(8) Scripps Institution of Oceanography, 1956, Data collected by Scripps Institution vessels on EASTROPIC expedition, September - December 1955. Scripps Institute of Oceanography, University of California, *SIO Reference*, **56** (28): 156 pp.

(9) Sette, O.E., 1955, Considerations of Mid-ocean Fish Production as Related to Oceanic Circulatory Systems, *Jour. Mar. Res.*, **14** (4): 398 - 414.

(10) Steemann Nielsen, E., 1937, On the Relation Between the Quantities of Phytoplankton and Zooplankton in the Sea, *Jour. du Cons. Int. Explor. Mer.*, **12** (2): 147-154.

(11) Sverdrup, H.U., Johnson, N.W. and Fleming, R.H., 1942, *The Oceans, Their Physics, Chemistry, and General Biology.* New York: Prentice-Hall, 1087 pp.

DISCUSSION

G.L. CLARKE: Zooplankton and forage animals are being reported in terms of standing crop, whereas the phytoplankton has been described in terms of production rate. The band of abundance of forage animals is three or more degrees of latitude away from that of zooplankton, and in interdependency between the two seems hard to understand.

A.C. HARDY: The drop in abundance of the zooplankton might be caused by the feeding of the forage animals.

A.L. TESTER: I acknowledge the disparity between production rates and standing crop, but I feel that because these two aspects are related, the purposes of the hypothesis concerning poleward movement during trophic succession can be examined even though we have no information on production rates of zooplankton and forage animals. The peaks of abundance of zooplankton and forage animals were separated latitudinally, but the two trophic levels were rather intimately mixed as one would expect.

R.W. HIATT: The apparently great distance between the peaks may not necessarily result from grazing or foraging activity. It was more likely due to the greatly overlapping latitudinal range of each trophic level.

G.L. CLARKE (Noting the smaller size of the day plankton catches.): How can copepods, which comprise the bulk of the catch, escape the net better during the day, because for the most part they have no eyes and therefore cannot see the oncoming net while vibration would be as effective during the night as during the day?

No reply was given to this question.

VARIATIONS IN YELLOWFIN ABUNDANCE IN THE CENTRAL EQUATORIAL PACIFIC

GARTH I. MURPHY and RICHARD S. SHOMURA

Pacific Oceanic Fishery Investigations, U.S. Fish and Wildlife Service, Honolulu, Hawaii.

In this paper we will discuss variations in the apparent abundance of deep-swimming yellowfin tuna (*Neothunnus macropterus* Temm. Schl.) in the vicinity of the Equator, and suggest a causal relation between variations in the environment and variations in catch rate. The study area, 150° - 155° W. longitude and 1° - 5° N. latitude, was surveyed several times by the Pacific Oceanic Fishery Investigations of the U.S. Fish and Wildlife Service during the period 1951 to 1954. A prominent and puzzling feature of the collective surveys is variation in the longline catches of deep-swimming yellowfin tuna, variation ranging from 2 to 10 fish per 100 hooks among crossings.

Though the discussion is confined to yellowfin tuna, we are utilizing them in a broader sense as an indicator of the general population of large carnivorous fishes. This population includes other species of tuna as well as sharks and spearfishes. In the area under consideration, yellowfin, for reasons as yet unknown, clearly dominate this fauna. Thus, consideration of them alone does not appear to violate sound ecological methodology, and considerably simplifies the arguments and presentation of results.

GEOGRAPHICAL VARIATION

Before considering temporal variability as such, a brief review of geographical variation in the study area and the equatorial circulation is in order, for we wish to advance essentially the same concepts in explaining temporal variation as have been employed in interpreting geographical variation in the physical environment and the abundance of organisms. Key references to this background material are Cromwell *(1)* (ocean circulation), King and Demond *(3)*, King and Hida *(4)* (plankton), Murphy and Shomura *(6,7,8)*, Shomura and Murphy *(10)*, and Iversen and Yoshida *(2)* (yellowfin tuna). In addition, a succinct general discussion of these data appears in Sette *(9)*.

The distribution of organisms is, of course, a function of the environment. In the tropical oceans, where physical conditions (e.g., temperature) are more or less uniform, it is likely that variations in such factors as basic productivity are of prime importance in controlling the distribution of fish. In the area under consideration the most important source of enrichment is the upwelling at the Equator first noted in the *Carnegie* section of 1929 *(11)*, and later more precisely described by Cromwell *(1)*.

The upwelling occurs at or near the Equator in the westerly flowing South Equatorial Current as a result of divergent flow created by the interaction of easterly winds and the Coriolis force. In other words, water is enriched at the Equator by upwelling and flows poleward within the framework of the westerly moving water mass. Geographically, water at the Equator is cool and rich in nutrients; poleward of the Equator the water is warmer and contains less nutrients, apparently the result of insolation and utilization.

The standing crop of zooplankton appears to vary according to expectation from the distribution of nutrients, for it is higher at the Equator than to the north and south, on the average. Frequently, however, the apparent center of abundance of zooplankton is displaced slightly poleward from the center of enrichment *(4)*. Because there is a poleward component in the surface currents, this displacement has been attributed to the time lag that must lapse between enrichment and the development of a zooplankton population.

Yellowfin tuna are also distributed in a manner compatible with our ideas of the circulation, but with a much greater poleward displacement of their peak abundance. Generally this displacement is to the north which is as expected, for Southeast Trades dominate this part of the equatorial Pacific, and under their influence the major poleward transport should be to the north. The more striking displacement of the tuna from the center of enrichment (as compared with zooplankton) is attributed to the interposition of one or more trophic levels between zooplankton and the tuna, and because the development of these must involve the passage of time, the geographical

distribution of tuna reflects this time lag by showing spatial displacement from the source of enrichment.

The net effect of the equatorial circulation is generally a concentration of yellowfin tuna between about 1°N. latitude and the southern boundary of the easterly flowing Countercurrent (about 5° N. latitude). Here, the effect of the equatorial enrichment is disrupted by the easterly flowing Countercurrent.

Reviewing these points, we have near the Equator, cool, enriched water which we will term *immature*. This water is high in nutrients and plankton but supports few yellowfin tuna. North of the Equator (1° - 5° N.) we have warmer, more *mature* water which is relatively poor in nutrients, has a lower standing crop of zooplankton, but supports relatively more tuna, presumably because of the larger standing crop of tuna forage. This relationship is illustrated by the results of a survey in September, 1951 (Fig. 1).

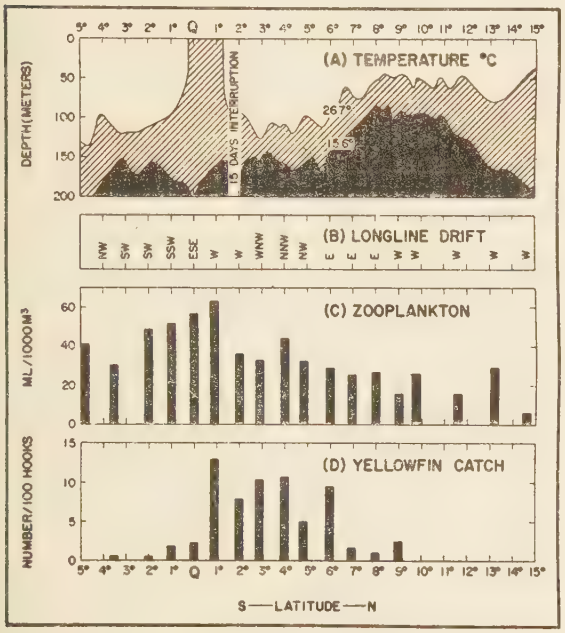

(A) TEMPERATURE °C
DEPTH (METERS)
15 DAYS INTERRUPTION
26.7°
15.6°
(B) LONGLINE DRIFT
NW SW SW SSW ESE W W WNW NNW NW E E E E E E W W W
(C) ZOOPLANKTON
ML/1000M3
(D) YELLOWFIN CATCH
NUMBER/100 HOOKS
5° 4° 3° 2° 1° Q 1° 2° 3° 4° 5° 6° 7° 8° 9° 10° 11° 12° 13° 14° 15°
S—LATITUDE—N

Fig. 1.—Diagrams of several fields resulting from a section along 150° W. longitude in September, 1951. (A) Temperature section from bathythermograms. (B) Direction of longline drift at each fishing station. (C) Volumes of zooplankton at each fishing station. (D) Yellowfin catch rate at each fishing station. *(Adapted from Sette 1955.)*

In seeking causes for variation in this situation we must return to the basic force controlling the upwelling and northward water movement. The wind systems that affect the equatorial upwelling undergo marked variations in force and direction. Presumably when the Trades are weak, the upwelling and northward displacement is sluggish, and when the Trades are strong, both the vertical and horizontal currents show an increase in velocity. We hypothesize that a period of continuous strong Trades should fill the entire zone between the Equator and the Countercurrent with immature, enriched water that supports few yellowfin. A pause or slackening of the wind system would slow down the circulation and result in mature water occupying the study area. This mature water should support a larger standing crop of yellowfin tuna.

As water temperature appears to be a useful measure of maturity when considering the synoptic geographical situation and was the only property of the environment consistently measured during fishing cruises, we elected to use it as the basic indication of water maturity in the zone between 1° and 5° N. latitude, 150° - 155° W. longitude. The hypothesis is that cool water in this zone is immature and contains few yellowfin, and that warm water is mature and well stocked with tuna. The inverse of this statement should apply to phosphate and zooplankton; that is, high phosphate and zooplankton should be associated with cool water. ((Presumably the area immediately south of the Equator could also be used as a test for the hypothesis, but unfortunately we lack adequate data.)

PHOSPHATE, ZOOPLANKTON, AND MATURITY

According to the hypothesis, variations in the concentration of inorganic phosphate and zooplankton along a north-south transect should be inversely related to temperature, providing consideration is restricted to the zone between the upwelling and the Countercurrent. Fig. 2 suggests that the hypothesis is supported by observation in that there appears to be a significant negative correlation between temperature on the one hand and phosphate and zooplankton on the other ($r = -.542$, $P < .01$ and $r = -.718$, $P < .01$ respectively).

The presentation in Fig. 2 might be criticized on the grounds that surface temperature is a relatively meaningless measure of the environment above the thermocline. Fortunately, in the zone north of the Equator, surface temperature is

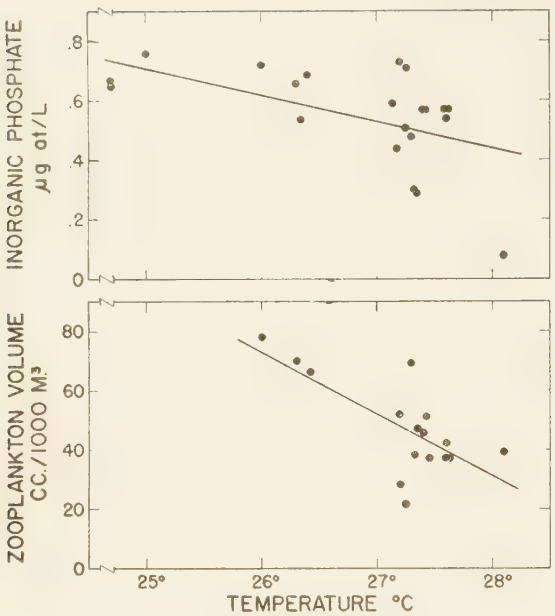


Fig. 2.—Phosphate (upper panel) and zooplankton (lower panel) as a function of water temperature (1° - 5° N. latitude, 150° - 158° W. longitude).

generally representative of the entire mixed layer, providing the effect of diurnal heating is suppressed. This has been done by using temperatures measured at about 30 feet (about 10 meters) below the surface.

The principal weakness in Fig. 2 lies in the small number of useable individual crossings of the study zone (4 in the instance of phosphate and 3 in the instance of zooplankton), for utilizing individual stations taken in north-south transects, as in Fig. 2, raises the possibility that the negative relations are merely a reflection of the parallel clines evident in north-south synoptic surveys (Fig. 1) and not evidence of temporal co-variation. Complete suppression of the effect of inherent geographical clines by using a mean value for each crossing as a single datum results in too few points on which to test any hypothesis. Nevertheless, a negative relation seems to persist when this is done, e.g., for phosphate and zooplankton in Fig. 3. There is no significance in the statistical sense, but this is to be expected with so few paired variates.

YELLOWFIN TUNA AND WATER MATURITY

Fortunately there are enough longline fishing sections (10) across the study area to treat a single crossing as a variate, thus completely suppressing the effect of clines within the zone. Over and above this fundamental need, it is also desirable to combine the results of several longline stations in order to suppress the high random variation of a single longline catch *(5)*.

The results of the longline catches (Fig. 4) are in surprising agreement with the prior hypothesis. Cool, immature water is associated with low

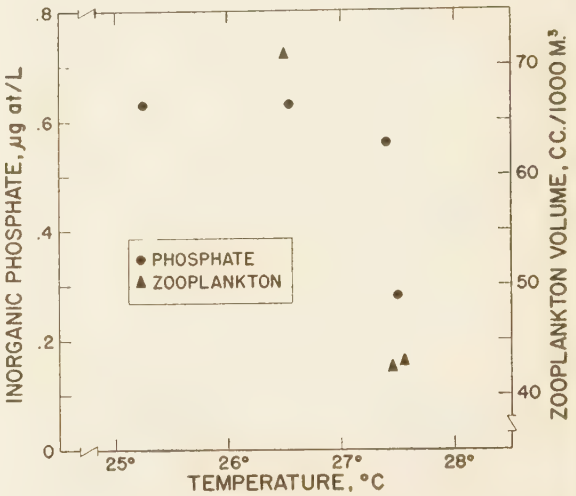


Fig. 3.—Inorganic phosphate and zooplankton catches as a function of temperature. Each point is the mean of the 4 or 5 stations taken during each transect of the 1°-5° N. zone.

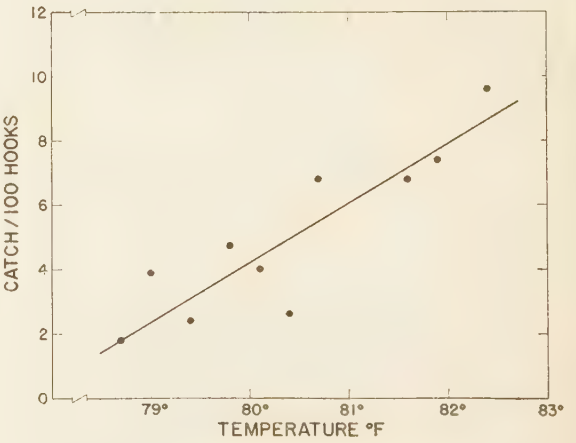


Fig. 4.—Yellowfin tuna abundance as a function of water temperature (1° - 5° N. latitude).

catches and warm, mature water with high catches. These same data replotted against time show the same striking relation between temperature and catch (Fig. 5). This latter analysis also shows that the relation described in Fig. 4 is not a reflection of coincidental, long-term, independent changes in the two variates (temperature and fish abundance).

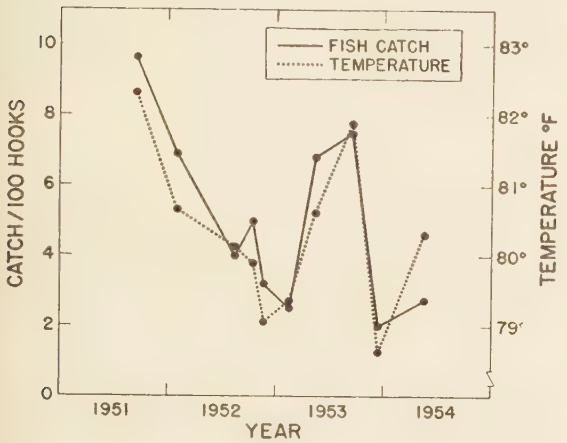


Fig. 5.—Temperatures and fish catches between 148°-155°W. longitude plotted against time.

SURFACE TEMPERATURE PROFILES

Treating temperature as an average in order to suppress inherent geographical clines tends to obscure the dynamic processes involved near the Equator, giving the impression that events there can be regarded as a succession of prolonged "steady states." Examination of the several cases at hand suggests, on the contrary, that the area is in a constant state of flux.

In interpreting the surface temperature profiles in Fig. 6, we regard the existence of a steep gradient in temperature between the Equator and the Countercurrent (about 5° N. latitude) as evidence of a rapidly changing situation, for such gradients are presumably caused by an upsurge in upwelling and northward flow. A shallow gradient or flat profile we regard as evidence of a situation at least temporarily stabilized. In the top panel are two curves indicating the effect of recent upwelling very near the Equator, with relatively warm, mature masses of water occupying most of the 1°-5°N. zone. These temperature situations were associated with good fishing. The middle panel shows the contrasting situation, with evidence of continuing upwelling at the Equator and the entire zone filled with cool, immature water. These temperature profiles were associated with very poor fishing. The bottom panel of Fig. 6 shows intermediate situations, the suggestion being that active upwelling has almost diplaced an existing mature body of water. The average catch was intermediate in magnitude.

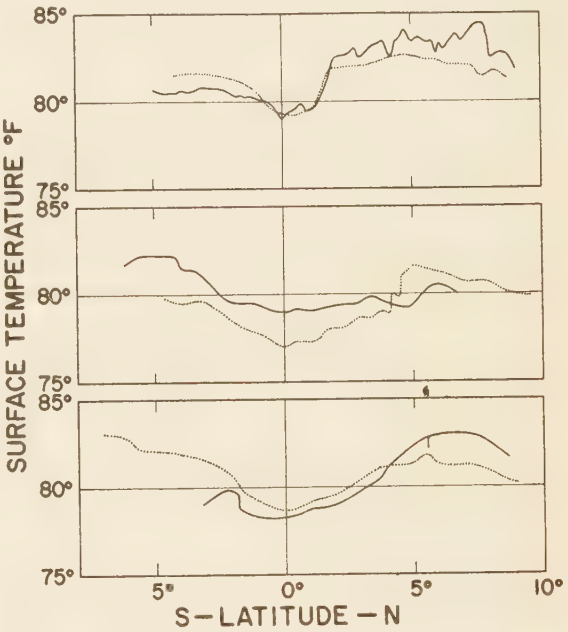


Fig. 6.—Temperature profiles associated with longline fishing stations along 150° - 155° W. longitude.

The interpretations above must be regarded as oversimplifications, because we are ignoring certain important factors, such as the westerly flow, that complicate any integration of the observed data. Nevertheless the temperature profiles do show that there are major temperature changes in this area ascribable to changes in the rate of upwelling and northward displacement rather than to simple changes in the rate of heat exhange in the area. Fluctuations in the amount of upwelling and northward displacement appear to affect the maturity of the water in the study area and thus the density of the population of yellowfin tuna.

DISCUSSION

We have been forced to ignore some of the complicating and poorly understood details of the water circulation in this presentation. Actually these details are not important to the main argument, for we are in general dealing with water that is cooler than "usual" for equatorial seas, in the sense that it has not come to equilibrium with insolation, and so we feel confident that it has been subjected to the influence of cooling and enrichment through upwelling in the not-too-distant past. Thus we have not been faced with, for instance, the problem of senescence that must eventually follow maturity (a problem which might well appear in a similar study at the same latitudes farther west, or if Countercurrent waters were considered). If additional knowledge of the circulation alters the concepts of the dynamics of the area, and thus the mechanisms that cause changes in the maturity of water in the study area, it seems unlikely they will alter our main theses that (1) temperature in the mixed layer is an index of maturity; (2) changes in maturity in the study area are a function of variation in the wind-driven circulation; and (3) within this area, changes in the density of yellowfin population are associated causally with changes in the relative maturity of the enriched water as evidenced by relative temperature.

In considering these results it must be borne in mind that only a minute area of the central Pacific is under scrutiny. Obviously this is not a complete account. We have assumed that yellowfin congregated in the study areas in response to increased food supplies. Presumably the reverse also occurs, that is, with an influx of cold, immature water being followed by dispersal of the tuna to other parts of the ocean. Though it does not seem to have occurred during the period of study, it is conceivable that the development of exceptionally favorable foraging conditions outside the study area might "draw off" the yellowfin somewhat independently of events in the study area itself. Finally, changes in the absolute size of the yellowfin population through variations in recruitment might affect the density of the population in the study area independently of changes in the area. The remarkable agreement between theory and empirical results suggests these factors have not varied materially during the period of the study.

A problem which cannot be ignored is that of assuming that catch rates are a measure of fish abundance. In the present instance, the longline appears to be a reasonably unbiased tool when fished in a standardized manner. On the other hand it is possible, though it does not seem probable at the moment, that the efficiency of the gear is drastically reduced as water clarity is reduced (particularly if vision is the first stimulus that directs the tuna towards the baited hook). Thus poor catches in the nutrient-rich, immature, cool water might be due in some degree to the tuna's finding it difficult to see the bait in waters made relatively turbid by an upsurge in phytoplankton abundance, and if this were true it would considerably weaken the arguments for our hypothesis.

SUMMARY

1. Ten longline fishing surveys across the Equator near 150° - 155° W. longitude in 1950-1954 showed variation in yellowfin catch rates of 2 to 10 fish per 100 hooks in the zone 1° - 5° N. latitude. An explanation of these variations is the subject of this paper.

2. Past studies have shown that in the vicinity of longitudes 150° - 155° W. there is active wind-induced upwelling at or near the Equator, and that upwelled water is transported poleward and westward. Temperatures are lower and the nutrient content of the ocean is higher at the Equator than poleward. Zooplankton is most abundant at or near the center of enrichment.

3. Tuna concentrations are generally well displaced from the nutrient and zooplankton centers, presumably because of the time lapse in development of the intermediate trophic levels, during which the enriched water is moving poleward from the Equator.

4. Heating takes place in the surface water following upwelling so the mature water that supports relatively large stocks of tuna is warmer than the cool, immature water supporting few tuna.

5. The geographical association of temperature with water maturity led to the hypothesis that temporal variations in tuna abundance in the zone 1° - 5° N. are a reflection of variations in water maturity in that zone, which variations should be reflected in the temperature of the mixed layer. Therefore, the explanation for geographical variation should also hold for temporal variation.

6. It is shown that zooplankton and phosphate north of the Equator show temporal changes negatively related to water temperature (= maturity).

7. Yellowfin tuna are most abundant in the zone north of the Equator when it is occupied by warm water which is believed to have achieved maturity subsequent to enrichment.

8. Evidence is given to show that changes in temperature in the study area are a reflection of changes in the rate of upwelling and northward displacement. Vigorous upwelling fills the study area with immature water, and the tuna population declines. Slowing of the upwelling results in the water which exists within the area being allowed to mature, and the tuna population then becomes denser.

BIBLIOGRAPHY

(1) Cromwell, T., 1953, Circulation in a Meridional Plane in the Central Equatorial Pacific, *Jour. Mar. Res.* **12** (2): 196-213.

(2) Iversen, E.S. and Yoshida, H.O., 1956, Longline Fishing for Tuna in the Central Equatorial Pacific, 1954, *U.S. Fish and Wildlife Serv. Spec. Sci. Rept.* (*Fish.*), **184**: 33 pp.

(3) King, J.E. and Demond, Joan, 1953, Zooplankton Abundance in the Central Pacific, *U.S. Fish and Wildlife Serv. Fish. Bull.*, **54** (82): 111-144.

(4) King, J.E. and Hida, T.S., 1957, Zooplankton Abundance in the Central Pacific, Part II, *U.S. Fish and Wildlife Serv. Fish. Bull.*, **57** (118): 365-395.

(5) Murphy, G.I. and Elliott, K.C., 1954, Variability of Longline Catches of Yellowfin Tuna, *U.S. Fish and Wildlife Serv., Spec. Sci. Rept.* (*Fish.*), **119**: 30 pp.

(6) Murphy, G.I. and Shomura, R.S., 1953a, Longline Fishing for Deep-Swimming Tunas in the Central Pacific, 1950-51, *U.S. Fish and Wildlife Serv. Spec., Sci. Rept.* (*Fish.*), **98**: 47 pp.

(7) ———, 1953b, Longline Fishing for Deep-Swimming Tunas in the Central Pacific, January-June, 1952, *U.S. Fish and Wildlife Serv., Spec. Sci. Rept.* (*Fish.*), **108**: 32 pp.

(8) ———, 1955, Longline Fishing for Deep-Swimming Tunas in the Central Pacific, August-November, 1952, *U.S. Fish and Wildlife Serv., Spec. Sci. Rept.* (*Fish.*), **137**: 42 pp.

(9) Sette, O.E., 1955, Consideration of Mid-ocean Fish Production as Related to Oceanic Circulatory Systems, *Jour. Mar. Res.* **14** (4): 398-414.

(10) Shomura, R.S. and Murphy, G.I., 1955, Longline Fishing for Deep-Swimming Tunas in the Central Pacific, 1953, *U.S. Fish and Wildlife Serv., Spec. Sci. Rept.* (*Fish.*), **157**: 70 pp.

(11) Sverdrup, H.U., Johnson, M.W., and Fleming, R.H., 1942, *The Oceans, Their Physics, Chemistry, and General Biology*. New York: Prentice Hall, 1087 pp.

DISCUSSION

M.S. DOTY: Have catches of tuna been made parallel to the Equator?

A.L. TESTER: Yes, but not in a way to be very meaningful.

F. NEAVE: What do tunas feed on, and has it been possible to sample the food organisms?

A.L. TESTER: They feed mostly on squid and fish, but unfortunately these types are not taken effectively by our present midwater trawl. I hope that we can devise a trawl in the future which will sample quantitatively the forage organisms taken by tuna.

Y. HIYAMA: We should take into consideration the appetite of the fish. It may be more important than the clarity of the water in the feeding process.

A.L. TESTER: The question of visibility of bait is being subjected to further intensive study.

Symposium: *Oceanography and Marine Resources of the Gulf of Thailand*

REPORT ON OCEANOGRAPHIC SURVEYS CARRIED OUT IN THE GULF OF THAILAND DURING THE YEARS 1956 - 1957†

COMDR. A. PENYAPOL, R.T.N.

Hydrographic Department, Royal Thai Navy, Thonburi, Thailand.

INTRODUCTION

It may be said that oceanographic work in Thailand has originated, as in most countries, from the hydrographic surveys. Tide observations are a necessary part of every hydrographic survey. These were started in our country in 1856. When Lt. Comdr. L. J. Bhrudhikrai, (now Admiral and Deputy Commander-in-Chief of the Royal Thai Navy) returned from the United States in 1923 after three years of extensive study in hydrography and oceanography, he recommended the establishment of an Oceanographic Division. The newly organized division was concerned with meteorological and oceanographic work. However, at that time, Lt. Comdr. Brudhikrai was the only oceanographer in Thailand and due to his valuable knowledge in other fields, he could not spare much time for this newly organized division, and progress was very slow. The meteorological work of this division progressed considerably and was later on separated from the Oceanographic Division and established as a new division in the Hydrographic Department.

Dredging of the Bangkok Bar Channel by the Ministry of Economic Affaires contributed to the progress of our tidal work. In 1937, the Royal Thai Navy was requested to send two officers from the Hydrographic Department to study the methods of tides and currents observations and river cross section, in connection with the harbor work. One of the officers was Lt. Sanit Mahagita (now Commodore and Deputy Director of the Hydrographic Department and Supervisor to Oceanographic Division). In 1937, the Section of Channel Investigation of the Department of Commerce was transferred to the Hydrographic Department. During this time, the tidal work had been expanded quite extensively. In addition to our tidal station at the Bangkok Bar, eighteen permanent stations had been established, eight along the Chao Phraya River (Menam River), nine in the Gulf of Thailand, and one on the western coast of the Malay Peninsula.

In 1942, the status of the Meteorological Division was raised to that of an independent department, and the Oceanographic Division was then reorganized into three sections: Physical Oceanography, Biological Oceanography, and Chemical Oceanography. A new program of sending our officers abroad for further study was subsequently initiated, but the outbreak of World War II prevented this from being carried out.

After the Second World War, in 1950, Captain (now Commodore) Sanit Mahagita was sent to observe tidal analysis work at Liverpool Tidal Institute in England and to procure a tide predicting machine from A. Legé & Co., England. Since then, all predictions of tides are made in our office, while formerly the results of the observations at the Bangkok Bar were sent to the U.S. Coast and Geodetic Survey, Washington, D.C. Our tide table now contains predictions of eleven different stations which is more than adequate for the commercial ships visiting Bangkok.

† This report, which appears in narrative form, contains the general information of oceanographic surveys carried out by the Hydrographic Department during the years 1956-57. It was our first attempt to conduct the physical oceanographic survey in the Gulf of Thailand. Most of the detailed planning was done by Commander Amporn Penyapol, R.T.N., Chief of the Hydrographic Investigation Division, under supervision of Commodore Sanit Mahagita, R.T.N., Deputy Director of the Hydrographic Department.

We wish to express our sincere appreciation to the Hydrographic Office of the U.S. Navy and the German Hydrographic Institute for their valuable advice and guidance. Thanks are also due Dr. A.F. Bruun of the Copenhagen Zoological Museum for his advice and valued criticism during his short visit to our office in early December, 1956.

Rear Admiral Vicharn Desakorn, Director, Hydrographic Department, Royal Thai Navy.

In 1951, one naval cadet and one officer were sent to study physical oceanography and chemical oceanography, respectively, at Liverpool University in England. One of these men has been assigned to the Physical Oceanographic Section and the other appointed Chief of the Chemical Oceanographic Section. In 1952, one officer was sent by USOM to the United States to further his training in tide and current observations at the U.S. Coast and Geodetic Survey, Washington, D.C., for a period of one year.

The Physical Oceanographic Section was concerned mostly with tidal work. Currents were observed, and sea water samples and sediment samples were collected during the course of various hydrographic surveys along the coast. Chemical analyses and sediment analyses were carried out by the Naval Scientific Division.

In 1954, a considerable sum was granted to the Hydrographic Department for building two oceanographic research vessels in Germany. After the delivery of these vessels, the previous oceanographic survey plan was revised, and a two year project was planned. At the beginning of 1956, an oceanographic survey party was organized, but the work could not be started until March, 1956. During this year an official of the Department of Fisheries was transferred to the Hydrographic Department. Graduates in physics, chemistry, and biology were also assigned to the Hydrographic Department to fulfill the need of personnel for this newly organized survey work.

In 1957, the survey party started its work in mid-February, and it was continued until the end of the year.

SURVEY PROJECT FOR THE YEARS 1956-57

As it was our first attempt to enter into the field of physical oceanography and because we did not have the assistance of an oceanographer in the planning stages, the survey project was drafted on a theoretical basis with the hope of modifying it after some practice cruises. The first project was submitted to the U.S. Navy Hydrographic Office and the German Hydrographic Institute for comments and suggestions. The replies, which were very encouraging, reached us at about the time we had finished our practice cruise in January, 1956. The preliminary survey project was then modified according to our experience from the practice cruise, and also the advice and suggestions of the U.S. Navy Hydrographic Office and the German Hydrographic Institute. The final project is summarized below.

Survey Areas (See Maps 1 and 2).

To facilitate the collection of data and its analysis, the Gulf of Thailand was divided into three areas with fixed stations as follows:

Area I—From Lat. 13° 00′ N. up to Bangkok Bar, oceanographic stations were established at a distance of five miles apart.

Area II—From Lat. 12° 30′N. to Lat. 13° 00′N., oceanographic stations were established at a distance of ten miles apart.

In Area I, the stations were spaced closely so that variations of temperature and salinity due to the effects of fresh water run-offs from four major rivers, monsoons, tides, and other factors could be easily observed. Complexity of oceanographic characteristics of the water in both areas is recognized.

Area III—From about a line joining Kelantan and Camao Point (or Cambodia Point) to about Lat. 12°30′N., observations will be made at stations established about 10 to 20 miles apart along both coasts, and various cross sections in the approximate direction of the northeast and southwest monsoons will be made at stations from about thirty to sixty miles apart.

Oceanographic Vessels

Two oceanographic vessels of about 90 tons each are available to work in Areas I and II and along the coasts in Area III. These two vessels were especially built for that purpose and are designated Oceanographic Vessel No. 1 and No. 2. They have a steel hull, are 28 meters long with 5.30 meters beam, and each is powered by one 240 h.p. diesel engine. The cruising speed is about $10\frac{1}{2}$ knots with a maximum range of about 2,000 miles. At present they are working at sea with a crew of twelve. Accommodations are available for two scientists on each vessel. The principal working space of each vessel is aft. Each vessel is provided with a hand winch and equipped with Atlas Echo-sounder, Muldedag and Askania bifilar current meter. A small space for a laboratory is also provided.

Cross sections of the Gulf must be made with a bigger vessel which is to be made available upon our request by the Navy. The cruise during November, 1956, to about the middle of January, 1957, was made by *M.F.V.* No. 9, which is actually a refrigeration vessel of about 400 tons, 43.5 meters long with 7.8 meter beam. She is powered

by one 600 h.p. diesel engine, has a cruising speed of 9½ knots, and a maximum range of 4,000 miles. Special booms were installed on both sides for lowering equipment because an oceanographic winch was not available. Two sounding machines were installed on both sides, the sounding wire was replaced by ¼ inch steel wire whose tested tensile strength is over one ton. Working space is amidship.

Observations at Various Stations

Stations in Areas I and II including stations in the coastal areas will be occupied at least once every month, while offshore stations along the cross sections will be occupied once every 3 or 4 months each year. The positions of the ship on every station in Areas I and II and in coastal areas are accurate to within ±0.5 mile, and positions of stations on cross sections are allowed to be within ±3 miles. At every station observations for the following will be made:

Temperatures: at stations with depth less than 20 meters, temperatures will be determined, and water samples will be collected at the following depths:

—at surface
—at 2.5 meters
—mid-depth
—at bottom.

At stations with depth over 20 meters, temperatures will be determined and water samples collected at the following depths:

—at surface	—at 30 meters
—at 5 meters	—at 40 meters
—at 10 meters	—at 50 meters
—at 20 meters	—etc., and at bottom.

These depths may be altered according to the characteristics of the water as determined from the results of Bathythermograph lowerings.

Bottom sampling: by snapping type sampler.

Transparency: by Secchi disk lowering.

Water color: by Forrel scale.

Meteorological data: by personnel assigned to each vessel by the Meteorological Department prior to each cruise.

Currents: occasionally, at locations specified prior to each cruise.

Biological specimens: collected occasionally, such as plankton hauling by net, sea weeds, corals, and rare specimens of fishes.

LIST OF PERSONNEL ENGAGED

Supervisor: Commodore Sanit Mahagita, R.T.N.

Chief oceanographic survey party: Commander Amporn Penyapol, R.T.N.

Assistant-Chief survey party: Lieutenant Comdr. Swarng Charernphol, R.T.N. B.Sc. (Hokkaido University)

Oceanographic Vessel No. 1 (90 tons):

Commanding Officer and Oceanographic Observer, Sub-Lieutenant Vichitr Sitotai, R.T.N.

Oceanographic Vessel No. 2 (90 tons):

Commanding Officer and Oceanographic Observer, Sub-Lieutenant Viphadhna Bhumisawati, R.T.N. (From March 17, 1956-January 31, 1957)

Sub-Lieutenant Cha-erb Sadubbundhit, R.T.N. (From January 31, 1957)

Motor Fishing Vessel No. 9 (400 tons):

Commanding Officer and Oceanographic Observer, Comdr. Amporn Penyapol, R.T.N. (October 22, 1956-January 11, 1957)

Junior Lieutenant Vibhadhna Bhumisawati, R.N.T. (from March 27, 1957)

Assistant Oceanographic Observers (Assigned alternately to each vessel):

Warrant Officer Bhinyo Chomsukprakit
Petty Officer Prachuab Suvanaridhi
Petty Officer Porn Parn-indra
Petty Officer Viratana Kinggaeo
Petty Office Asany Saomanee
Petty Officer Chalae Yamsri
Petty Officer Vicharn Boonyuan
Petty Officer Chamnarn Mingmitra
Petty Officer Somsuk Chanpechara

Scientific Staff:

Chemists—

Lieutenant Prapas Singhaseni, R.T.N., M.Sc. (Liverpool)

Sub-Lieutenant Uraichome Na-Thalang, R.W.T.N., B. Sc. (Chulalongkorn University)

Sub-Lieutenant Suchati, R.T.N., B.Sc. (Chulalongkorn University)

Physicists—

Sub-Lieutenant Arvorn Supyasiri, R.W. T.N., B. Sc. (Chulalongkorn University)

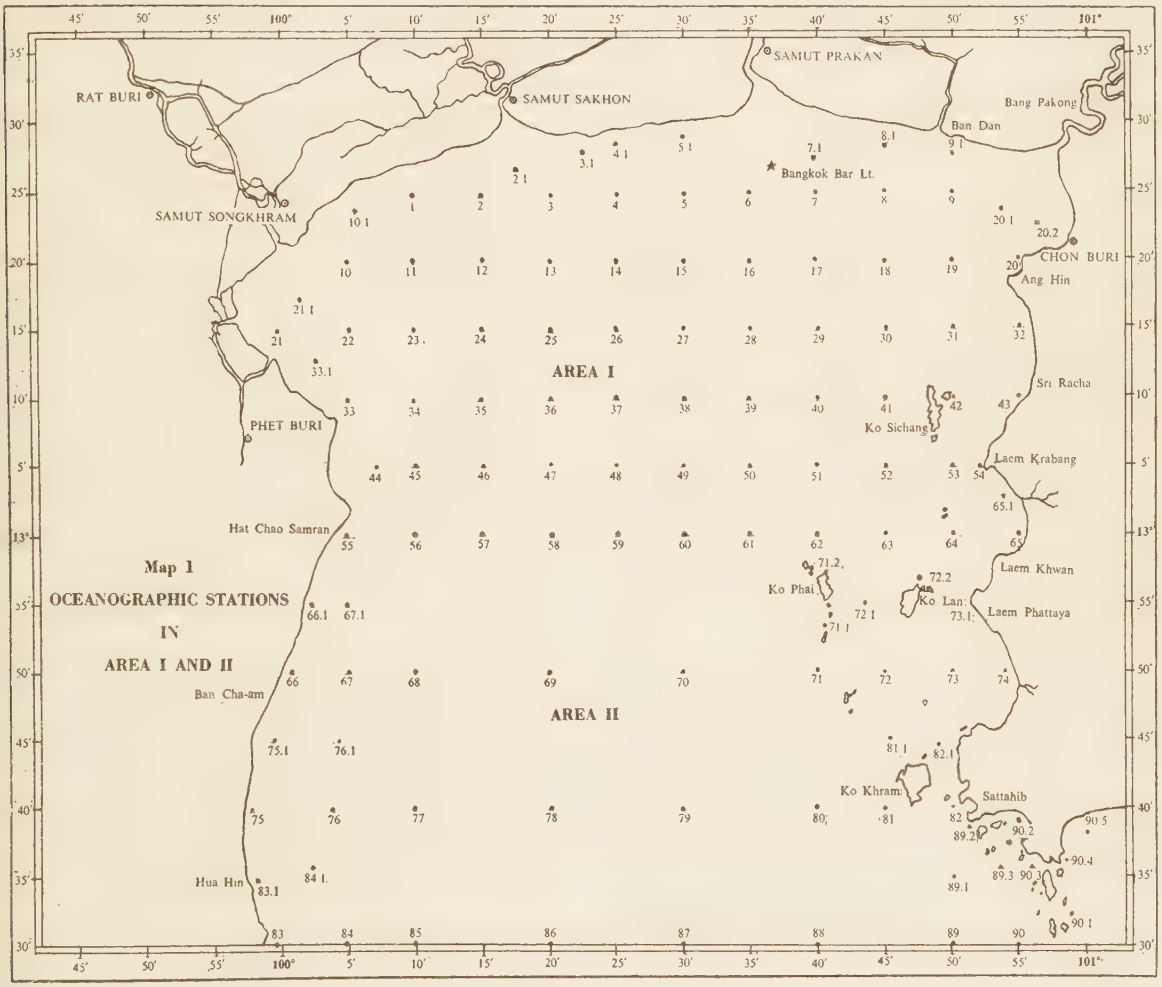
Sub-Lieutenant Parvej Pochanasomburana, R.T.N., B. Sc. (Liverpool)

Biologists—

Lt. Charlie Devahastin, R.T.N., B. Sc. (Tokyo University)

Sub-Lieutenant Thavatchai Thaiyong, R.T.N., B. Sc. (Chulalongkorn University).

Map 1.



CRUISES DURING THE YEAR 1956

During the year 1956, several cruises were made as shown in the following table.

Total working days at sea (the days oceanographic work was actually done) of all cruises were much less than total days at sea. This was due, in part, to the fact that the cold storage space on board each vessel is limited, and both vessels had to call at some ports for fresh provisions. Some days were also spent travelling to various tidal stations and to some remote working areas, which were not counted as working days.

Table 1.
Cruises made in 1956.

Vessel	Cruise No.	Date		Total days	
		From	To	At Sea	Working
Oceanographic Vessel No. 1	1/99	4 January	10 February	34	28
	2/99	1 March	15 March	13	11
	3/99	16 April	16 May	28	13
	4/99	1 June	1 July	28	12
	5/99	16 July	16 August	29	17
	6/99	1 September	30 September	28	16
	7/99	15 October	14 November	28	15
	8/99	21 November	6 December	13	4
Oceanographic Vessel No. 2	1/99	7 March	16 April	28	17
	2/99	1 May	1 June	29	16
	3/99	23 June	23 July	28	14
	4/99	8 August	7 September	28	16
	5/99	20 September	19 October	28	19
	6/99	5 November	10 December	32	18
Motor Fishing Vessel No. 9	1/99	22 November	10 January, 1957	48	20

Cruise 1/99 of vessel No. 1 was in part a joint hydrographic survey of the intended site of a new harbor, with extra work on currents and surface drift observations and collection of sediment samples. Cruise 2/99 was to instruct personnel on observation methods and to familiarize personnel with all oceanographic equipment being used on board.

Cruise 1/99 of *M.F.V.* No. 9 was actually made in two parts, the first part from November to December and the second part from December to January, 1957. During the first part of the cruise the vessel encountered very rough sea and had to take shelter at Ko Samui for many days. As a result, only three cross sections were accomplished. Later on, the vessel had to come back for provisions, fresh water, and also for minor repairs. All cross sections according to the preassigned plan were accomplished. (See Map 3 of Cross section track and Map 4 showing salinities of surface water.)

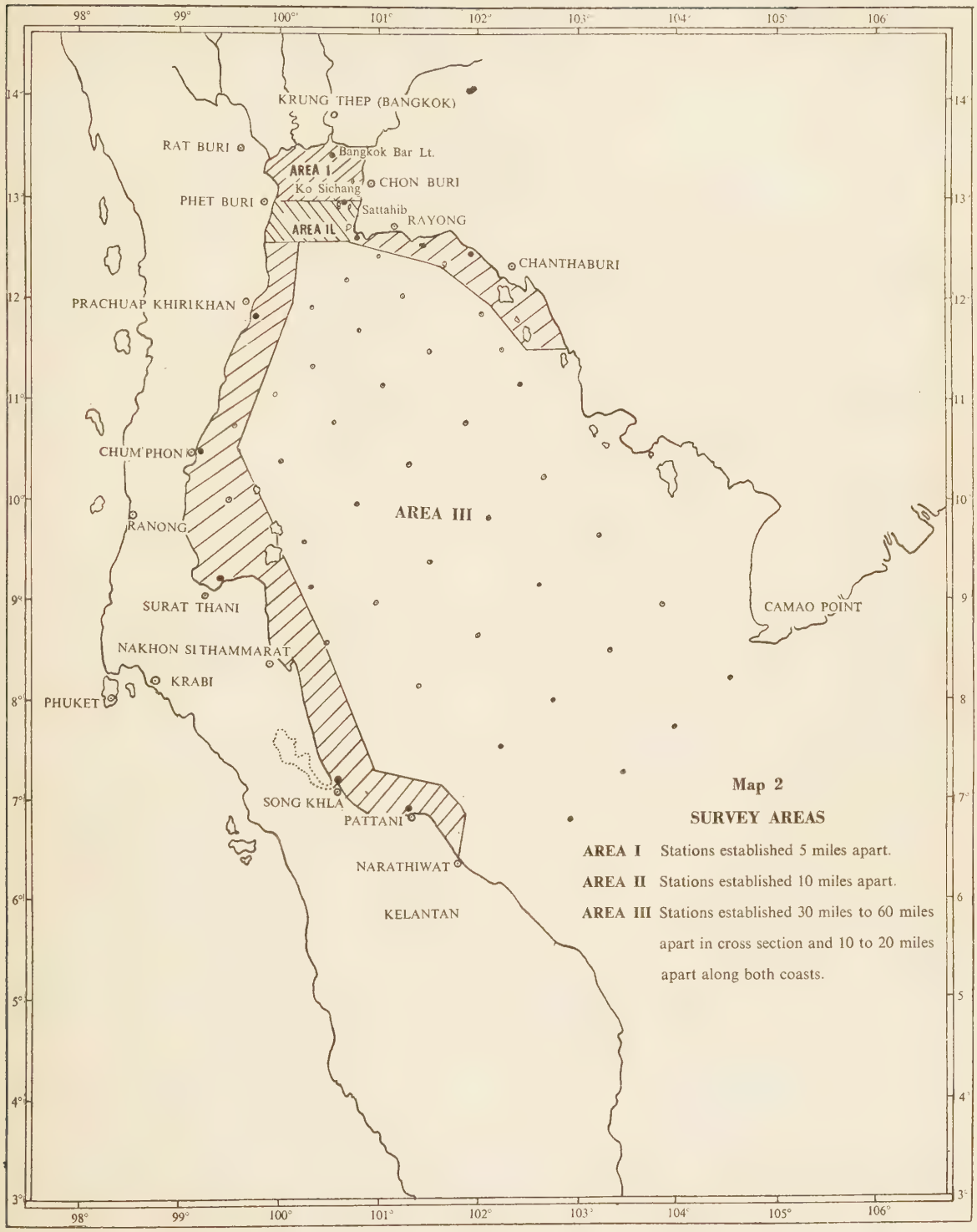
Cruise No. 5/99 of vessel No. 1 included special arrangement of a field trip for students of the Biology Department, Chulalongkorn University.

CRUISES MADE DURING 1957

Owing to our routine, we have to submit recommendations to the Navy for oceanographic survey work for approval in January, because the Navy cannot issue any order effective for more than one year. We submitted our recommendation a little too late, consequently, the first cruise of 1957 could not be made until mid-February.

In 1957, all cruises were extended to 45 days instead of 30 days as in the previous year. This is due to a slight modification of the working plan

Map 2.


98°
99°
100°
101°
102°
103°
104°
105°
106°
14°
13°
12°
11°
10°
9°
8°
7°
6°
5°
4°
3°
KRUNG THEP (BANGKOK)
RAT BURI
Bangkok Bar Lt.
AREA I
Ko Sichang
CHON BURI
PHET BURI
Sattahib
AREA II
RAYONG
CHANTHABURI
PRACHUAP KHIRIKHAN
CHUM PHON
AREA III
RANONG
SURAT THANI
CAMAO POINT
NAKHON SITHAMMARAT
KRABI
PHUKET
SONG KHLA
PATTANI
NARATHIWAT
KELANTAN
Map 2
SURVEY AREAS
AREA I Stations established 5 miles apart.
AREA II Stations established 10 miles apart.
AREA III Stations established 30 miles to 60 miles apart in cross section and 10 to 20 miles apart along both coasts.

which decreased the number of stations occupied in Areas I and II and also in coastal areas so that more time could be spent on current observations and biological study in remote areas. Cruises made during this year are shown in Table 2.

full cooperation had been given to Dr. Robert R. Harry-Rofen and Mr. H. Adair Fehlmann of Stanford University and the Vanderbilt Foundation in carrying out their research work in the Gulf of Thailand during Cruise No. 2/2500.

Table 2.
Cruises made in 1957.

Vessel	Cruise No.	Date		Total days	
		From	To	At Sea	Working
Oceanographic Vessel No. 1	1/2500	12 February	18 May	40	18
	2/2500	18 June	1 August	37	17
	3/2500	17 August	30 October	36	16
	4/2500	16 October	30 November	—	—
Oceanographic Vessel No. 2	1/2500	4 March	18 April	43	17
	2/2500	5 July	29 August	41	21
	3/2500	5 September	29 October	42	13
	4/2500	5 November	30 December	—	—
Motor Fishing Vessel No. 9	1/2500	20 May	18 July	21	7
	2/2500	16 October	29 December	—	—

Special duties were occasionally carried out by both vessels during various cruises of this year. Field trips were specially arranged for the students of the Biology Department of Chulalongkorn University, and also for students of College of Fishery, Kasetsart University. The latter were on board Oceanographic vessel No. 2 for five days, and observed and practiced techniques of oceanographic observations under supervision of one of our officers who is a lecturer on Oceanography at Kasetsart University.

It was evident from cruises of both years that our two oceanographic vessels could be used very satisfactorily to a distance of about thirty miles offshore. Cross sections of the Gulf had been attempted by the two vessels, but they rolled quite heavily in a moderate sea. These two vessels could still be used satisfactorily in a moderate sea with wave heights under five feet. In 1956, the two vessels encountered a typhoon, during which one merchant ship (*M.V. Lakorn*) was sunk, and a maximum record inclinometer reading of 33° was obtained.

The *M.F.V.* No. 9 could be used successfully in making cross sections of the Gulf. If there were more accommodation space for a few more scientists and also for laboratory work, she would be more suitable for oceanographic work. However,

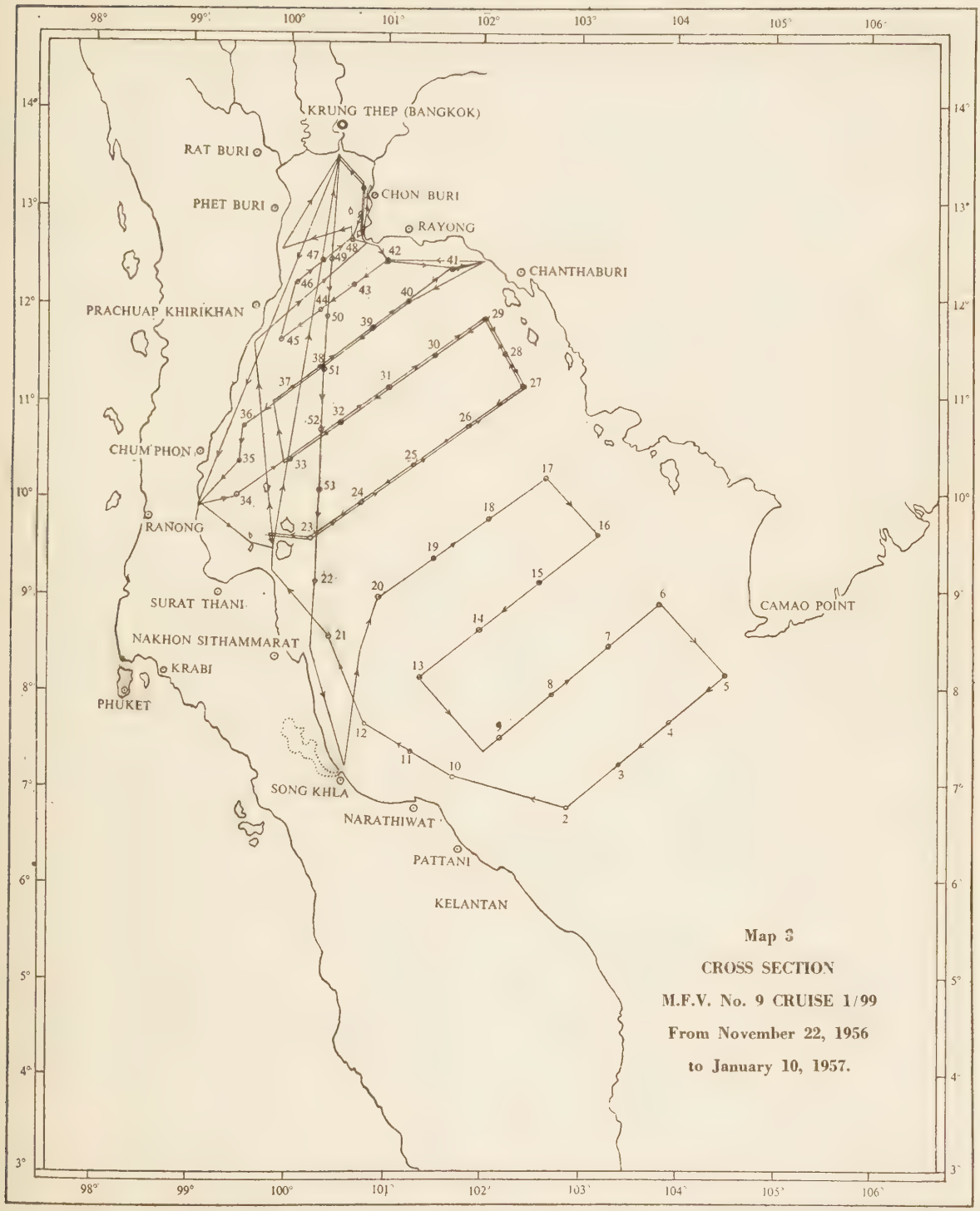
Special arrangements were also made for Dr. Shepard, Dr. Emery, and Dr. Niino to collect bottom sediments in the Gulf of Thailand after the Ninth Pacific Science Congress.

OCEANOGRAPHIC EQUIPMENT AND METHOD OF OBSERVATIONS

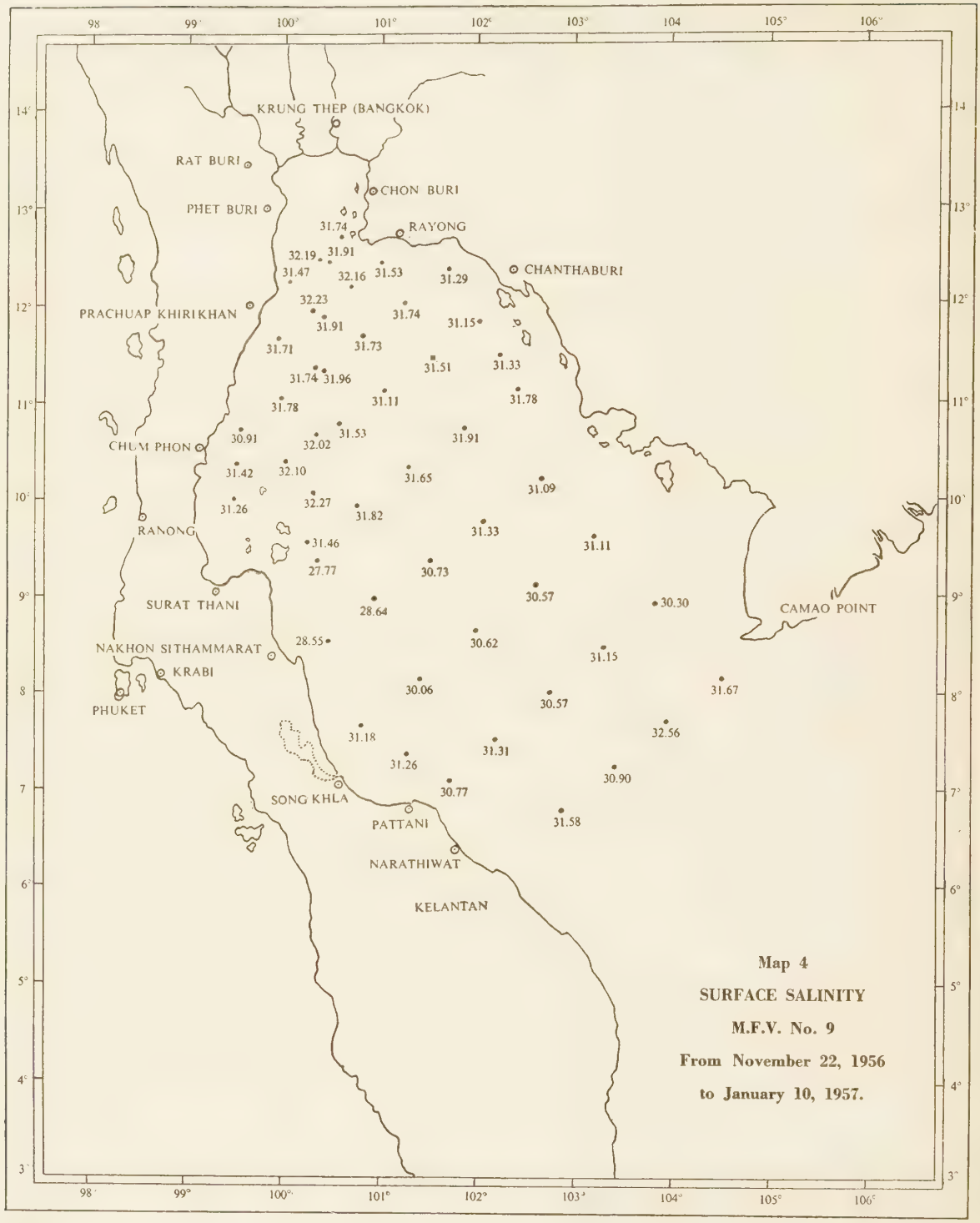
Prior to 1956, only a few Ekman bottles and 14 reversing thermometers (protected type) were available, but the Department of Fisheries has kindly loaned 4 Nansen bottles, *BT*'s, meter wheels, and other equipment as well. Only one hand winch is provided on board each oceanographic vessel except the *M.F.V.* No. 9 on which sounding machines are installed. Equipment for collecting biological specimens are also lacking. When the three vessels are working at sea at the same time, the equipment must be distributed to each vessel, and thus considerable time must be spent at each station occupied.

Water samples at various depths were collected with Nansen and Ekman bottles. The latter were usually used at bottom depths. Surface water samples were collected by bucket, and temperature readings were taken immediately by precise thermometers. Temperatures at other depths were determined by reversing thermometers, a

Map 3.


KRUNG THEP (BANGKOK)
RAT BURI
PHET BURI
CHON BURI
RAYONG
CHANTHABURI
PRACHUAP KHIRIKHAN
CHUM PHON
RANONG
SURAT THANI
NAKHON SITHAMMARAT
KRABI
PHUKET
SONG KHLA
NARATHIWAT
PATTANI
KELANTAN
CAMAO POINT
98°
99°
100°
101°
102°
103°
104
105°
106°
14°
13°
12°
11°
10°
9°
8°
7°
6°
5°
4°
3°
Map 3
CROSS SECTION
M.F.V. No. 9 CRUISE 1/99
From November 22, 1956
to January 10, 1957.

Map 4.


KRUNG THEP (BANGKOK)
RAT BURI
CHON BURI
PHET BURI
RAYONG
CHANTHABURI
PRACHUAP KHIRIKHAN
CHUM PHON
RANONG
SURAT THANI
NAKHON SITHAMMARAT
KRABI
PHUKET
SONG KHLA
PATTANI
NARATHIWAT
KELANTAN
CAMAO POINT
31.74
32.19
31.91
31.47
32.16
31.53
31.29
32.23
31.74
31.91
31.15
31.71
31.73
31.51
31.33
31.74
31.96
31.78
31.11
31.78
30.91
32.02
31.53
31.91
31.42
32.10
31.65
31.09
31.26
32.27
31.82
31.33
31.46
31.11
27.77
30.73
30.57
30.30
28.64
28.55
30.62
31.15
30.06
31.67
30.57
31.18
32.56
31.31
31.26
30.90
30.77
31.58
Map 4
SURFACE SALINITY
M.F.V. No. 9
From November 22, 1956
to January 10, 1957.

pair of which were attached to each Nansen bottle. Air temperatures were observed on the bridge about ten feet from the surface. *BT* lowerings were made mostly at stations whose depths are over forty meters. It is very unfortunate that the *BT*'s available are deep type, and thus *BT* observations were not processed, but only utilized in predetermining depths for each cast.

Small grab samplers were used for collecting sediment samples. A core sampler of similar design to Kullenberg's was recently made at the Naval Dockyard, but it has not been tested for operation yet.

During these two years only a few plankton haulings were made on surface for general study. Specimens of fishes were also collected and preserved for our museum.

Meteorological observations during each cruise were made by personnel from the Meteorological Department assigned to each vessel.

ANALYSIS OF SEA WATER AND SEDIMENTS

Most of the sea water samples collected during various cruises in 1956 were sent to the Naval Science Department, Ministry of Industry. The results were not satisfactory owing to the fact that chemists were not familiar with the standard Knudsen method. However, at the beginning of 1956, two chemists, graduates of Chulalongkorn University, were assigned to our Chemical Oceanographic Section, and practiced titration by Knudsen method. Until early in October of the year, the Chemical Oceanographic Section was able to analyze sea water. Owing to the lack of laboratory equipment and very limited space, the samples were analyzed only for salinity. Being fully aware of the necessity of a well equipped laboratory, we submitted a recommendation for the establishment of a laboratory at Sattahib Naval Training Station, and it was duly approved. However, its construction could not be started until in late August, 1957; and the completion is expected in 1958.

Only about 100 sediment samples were collected during cruises of both years, and their analyses could not be undertaken in our office. However, the Department of Engineering, Chulalongkorn University, kindly gave access for our personnel to their Soil Laboratory. All samples were then analyzed for grain size and water content, but the results are not consistent owing to an insufficient amount of each sample collected. Our grab samplers are too small and too light to use in deep water. They often failed to work, and consequently several casts had to be made before about 150 grams of bottom sediments could be obtained. In later cruises, the sediments were thus collected and analyzed crudely on board the vessel for their general characteristics.

PROCESSING OF DATA

Oceanographic data collected were processed by the method described in H.O. Publication No. 614, *Processing Oceanographic Data*, of which many copies were made available to our office by the U.S. Navy Hydrographic Office, Washington, D.C. Many oceanographic log sheets from the same office have been adapted for use in our work.

CONCLUSION

Close examination of results from surveys carried out during these two years indicates that the survey work has not yet fully achieved the objective aimed for in our project. However, one major achievement has been reached, that is, the experience gained by our personnel. In the future, when more equipment and specially trained personnel are available, our work can be improved.

DISCUSSION

A.F. BRUUN: I have followed the development of Thailand's oceanographic program and congratulate Thailand on its progress in such a short time.

K. HIDAKA: What kind of tide-predicting equipment is used in Thailand?

A. PENYAPOL: We use the tide predicting machine of 32 components designed by Dr. Doodson of the Liverpool Tidal Institute, England.

The Chairman, Tham Ah Kow, speaking for the whole group, added general congratulations to Thailand for the fine progress evident so soon after initiation of oceanographic work.

PRELIMINARY RESULTS OF A PRE-CONGRESS BIOLOGICAL SURVEY IN THE GULF OF THAILAND

R.R. HARRY-ROFEN and H. ADAIR FEHLMANN

George Vanderbilt Foundation, Natural History Museum, Stanford University, Stanford, California, U.S.A.

(A verbal report by the senior author.)

DISCUSSION

A.L. TESTER: Can the differences found in the reef fauna of the Gulf of Thailand from that of more open areas be attributed to differences in environment? Is the water less turbid around the East Indies?

R.R. HARRY-ROFEN: There are environmental differences, but the literature suggests that waters are turbid in the East Indies.

A.L. TESTER: Could the center of the Indo-Pacific fauna be somewhat east of the Gulf of Thailand, with subsequent movement to both east and west?

R.R. HARRY-ROFEN: Results of this survey show that the fauna of the Gulf of Thailand differs appreciably from that of the East Indies. Perhaps the origin of the Gulf of Thailand fauna is from the east, but recent studies in the Indian Ocean above east Africa reveal this region to be a center of origin for at least part of the Gulf of Thailand fauna.

A.F. BRUUN: Since the Gulf of Thailand was dry land only 15,000 years ago, its study can reveal the selection process in a newly developing environment.

R.R. HARRY-ROFEN: Essentially the same is true of central Pacific atolls, and endemism of the reef fauna is apparent. Since the enduring organisms often are not present outside the lagoons, one wonders where they lived during the dry period.

F.P. SHEPARD: One might expect the large amount of sediment entering the Gulf of Thailand from the north to have a considerable effect on the fauna. Does the endemism mentioned in the Gulf refer only to brakish water and the sea close to islands?

R.R. HARRY-ROFEN: No, I was referring to primary freshwater fishes, confined entirely to freshwater streams. The origin of these fishes on the islands must have occurred during connected river drainage, when the islands were part of the mainland.

SALINITY AND TEMPERATURE VARIATIONS OF THE SURFACE WATER IN THE UPPER PART OF THE GULF OF THAILAND†

COMDR. A. PENYAPOL, R.T.N.

Hydrographic Department, Royal Thai Navy, Thonburi, Thailand.

(Abstract)

The upper part of the Gulf of Thailand, between Lat. 12° 30′ N. and Bangkok Bar, is constricted, with constant inflows of fresh water from four major rivers. Data collected during the years 1956 and 1957 show that the southwest and northeast monsoons have a preponderant affect on salinities of the surface water.

DISCUSSION

R.L. BOLIN: Off the Pearl River (near Hong Kong), the effect of outflow on salinity is confined to the near-surface. Is this true in the Gulf of Thailand?

A. PENYAPOL: We collected water samples at various depths, the results of which cannot be reported at this time. The discussion here refers to surface water.

K. HIDAKA: Is it possible to infer current from the surface temperature and salinity data already obtained?

A. PENYAPOL: A detailed study has not been made. From our field experience, we may say that there is a strong current running along the east coast and that the littoral current is running almost west-east.

THAM AH KOW: In the Gulf, the current appears to rotate clockwise throughout the year.

† The manuscript was not available at the time of going to press.—*Editor*

THE TYPES OF TIDES AND MEAN SEA LEVEL IN THE GULF OF THAILAND

LT. COMDR. PINICH PUKASAB, R.T.N. and SUB. LT. PRAVEJ POCHANASOMBURANA, R.T.N.

Hydrographic Department, Royal Thai Navy, Thonburi, Thailand.

The measurement and study of tides involves the selection of a water level from which tidal variations can be determined. In order that our charts may show the least depth of water under ordinary conditions, the level chosen is approximately that of the lowest level to which the tide ordinarily falls. When our charts depend on the surveys of other nations, the datum used is that of the original chart, and this may be appreciably higher or lower than that ordinarily used. If the height of the tide above datum is calculated for any particular time, it has only to be added to the charted depth of water to give the depth at that time. If the height is negative, it must be subtracted from the depth.

Our tidal studies are based on the Analysis of Tidal Observations for 29 days, i.e., T.I. method (by A.T. Doodson).

In order to predict the height of the tide at any place with accuracy, extensive tidal observations must be carried out, and the results analyzed. For the purpose of this analysis, the terrestrial wave is assumed to be formed by a number of simple harmonic constituents, hence the name, harmonic tidal analysis. Of these terrestrial constituents, the two most important are:

1. The principal lunar semi-diurnal constituent; this constituent is referred to by the symbol M_2.

2. The principal solar semi-diurnal constituent; this constituent is referred to by the symbol S_2.

Each of the other constituents introduces a different factor, such as parallax and declination, which alters the tide-generating forces. The periods and phases of these equilibrium constituents can be calculated, for any given time, from the known movements of the earth and moon relative to the sun.

For the sake of convenience, these constituents are called diurnal or semi-diurnal as their periods are approximately 24 h. or 12 h. Each constituent is distinguished by a capital letter, i.e., K_1 and O_1. K_1 is the lunisolar declinational constituent, and O_1 is the lunar declinational constituent.

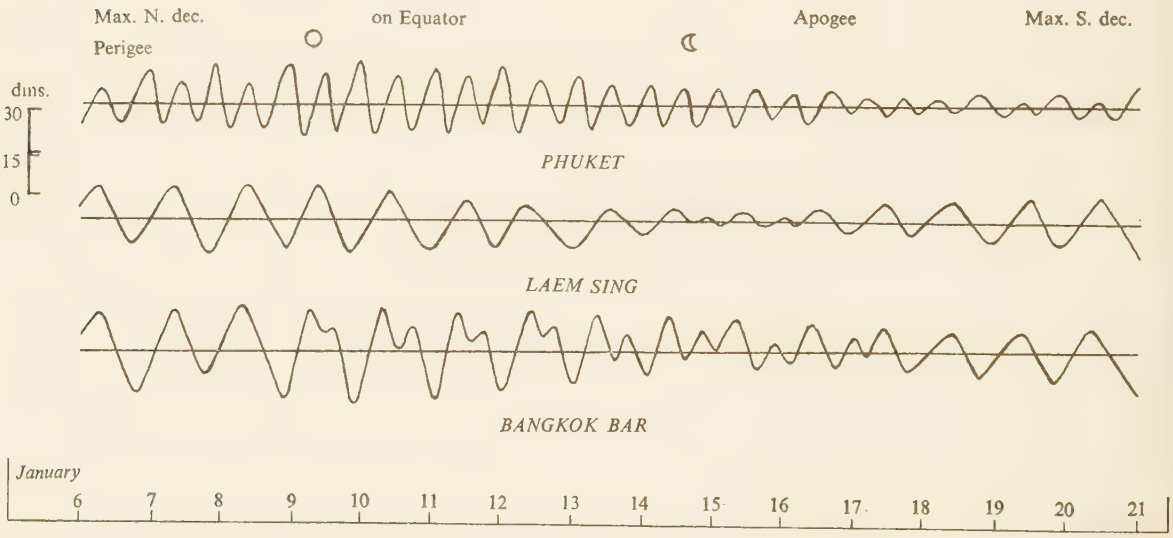


Fig. 1.—Types of tide curves from stations along the coast of Thai waters during January 6 to 20, 1955.

Every terrestrial constituent lags behind its corresponding equilibrium constituent, and its amplitude is not that of the equilibrium constituent. It can, however, be defined as H, and g, where H is amplitude and g is the phase lag, adjusted to the standard time kept at the place.

At some places, the diurnal inequalities K_1 and O_1 are so large that only one high water occurs each day. The tides so formed are called "Single Day Tides." But mostly the tides which occur in Thai waters are a mixture between semi-diurnal and diurnal tides.

The three types of tide in the Thai waters are illustrated in Fig. 1, i.e., the tide curves for a period of 15 days for Phuket (west coast of Malay Peninsula), Laem Sing, and Bangkok Bar, from January 6 to January 20, 1955.

In Fig. 1, the upper curve, is for Phuket. It illustrates the semi-daily type of tide, i.e., two high and two low waters in a day.

The middle curve, for Laem Sing, illustrates the daily type of tide, i.e., only one high and one low water in a day.

The lower curve is for Bangkok Bar. It illustrates one form of the mixed type, i.e., probably two highs and two lows or one high and one low water in a day.

For technical purposes, we must classify the types of tides in Thai waters. The formula we have used is based on the harmonic constants of tides, i.e., the ratio of K_1+O_1 to M_2+S_2, where K_1 and O_1 represent the amplitude of the principal daily constituents of tide and M_2 and S_2 represent the principal semi-daily.

These ratios are classified as follows:

$0 < \frac{K_1+O_1}{M_2+S_2} < 0.25$	Tide is regular semi-diurnal.
$0.25 < \frac{K_1+O_1}{M_2+S_2} < 1.15$	Tide is semi-diurnal with inequalities.
$1.15 < \frac{K_1+O_1}{M_2+S_2} < 3.00$	Tide is mixed types between diurnal and semi-diurnal.
$3.00 < \frac{K_1+O_1}{M_2+S_2}$	Tide is diurnal.

The values of $(K_1+O_1)/(M_2+S_2)$ all over the Gulf is illustrated in Figure 2.

Table 1 lists the locations, positions, the ratio of the main constituents, and the types of tide at various points in Thai territory.

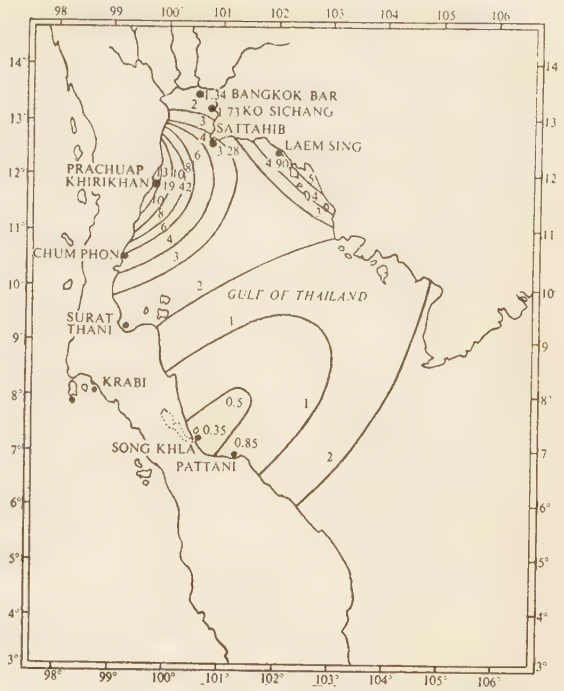


Fig. 2.—The values of $(K_1+O_1)/(M_2+S_2)$ all over the Gulf.

Our tide studies have been operating since 1916. We first built a tidal station at Bangkok Bar, and in the following year we built three more stations. Most of the work was carried out just before the Second World War, and in 1939, we had about ten tidal stations. During the war we encountered a lot of obstacles. Therefore, our work did not progress until 1949, but we kept it operating as well as we could.

Now we have sixteen tidal stations, mostly along the coast and at the mouths of the rivers. In 1958, we will probably have at least twenty-one stations.

THE OBSERVATION OF MEAN SEA LEVEL

Mean sea level is defined as the average height of the sea calculated from a long series of observations obtained at equal intervals of time. For monthly mean, it is carried to two decimal places; and the results are entered at the bottom of the sheet containing the record for the last day of the month. It also provides for an accumulative mean combining all yearly means up to date. Determi-

Table 1.

List of tidal stations in Thai waters.

Locations	Positions		$\frac{K_1+O_1}{M_2+S_2}$ =		Types of Tides
	Lat.	Long.			
1. Pattani	6° 57′ 00″N.	101° 17′ 36″E.	$\frac{1.219+1.732}{2.103+0.183}$ =	0.85	Semi-diurnal with inequalities
2. Song Khla	7° 14′ 11″N.	100° 36′ 54″E.	$\frac{0.542+0.365}{2.258+0.335}$ =	0.35	Semi-diurnal with inequalities
3. Ko Prab	9° 13′ 12″N.	99° 25′ 15″E.	$\frac{4.694+3.168}{1.979+1.365}$ =	2.35	Mixed Diurnal+ Semi-diurnal
4. Chum Phon	10° 26′ 40″N.	99° 15′ 08″E.	$\frac{4.023+2.682}{1.219+0.396}$ =	4.15	Diurnal
5. Ko Lak (Pra-chuap Khirikhan)	11° 48′ 00″N.	99° 49′ 00″E.	$\frac{5.096+3.486}{0.512+0.131}$ =	13.35	Diurnal
6. Mae Klong Bar	13° 21′ 00″N.	99° 59′ 00″E.	$\frac{6.553+4.267}{4.602+2.134}$ =	1.61	Mixed Semi-diurnal + diurnal
7. Tachin Bar	13° 33′ 00″N.	100° 15′ 00″E.	$\frac{6.706+4.420}{5.243+2.804}$ =	1.38	Mixed Semi-diurnal + diurnal
8. Bangkok Bar	13° 26′ 31″N.	100° 36′ 16″E.	$\frac{6.816+4.488}{5.580+2.843}$ =	1.34	Mixed Semi-diurnal + diurnal
9. Bang Pakong	13° 30′ 04″N.	100° 59′ 11″E.	$\frac{5.978+3.912}{5.181+2.339}$ =	1.32	Mixed Semi-diurnal + diurnal
10. Ko Sichang	13° 09′ 10″N.	100° 49′ 15″E.	$\frac{6.675+4.572}{4.511+1.980}$ =	1.73	Mixed Semi-diurnal + diurnal
11. Sattahib	12° 38′ 42″N.	100° 52′ 55″E.	$\frac{6.401+4.578}{2.438+0.914}$ =	3.27	Diurnal
12. Laem Sing	12° 28′ 27″N.	102° 03′ 45″E.	$\frac{5.883+4.572}{1.640+0.488}$ =	4.90	Diurnal
13. Phuket	7° 50′N.	98° 26′E.	$\frac{1.280+0.549}{7.620+3.810}$ =	0.16	Regular Semi-diurnal

nation of mean sea level depends largely upon the number of years of observations.

If the level of the sea were to fluctuate only in response to daily and semi-daily tide-producing forces of unvarying periods, then mean sea level could be determined from one day of tidal observation. Averaging the hourly heights of the tide through one day, the effect of the tide would then be eliminated, the resulting average height being the height of mean sea level. But the tide-producing forces to which the sea responds include, besides those of daily and semi-daily periods, also those with periods of half a month or more. Daily sea level, therefore, varies from one day to another in consequence of these so-called long period tides.

Mean sea level should be applied to the data derived from observations taken on the open coast. In Thai waters, we chose Prachuap Khirikhan and used this as the standard. Its mean sea level is about 25.0 dms. above the zero of its tidal staff, and most of the places have mean sea level referred to Prachuap Khirikhan.

The following list is for mean sea level, springs rise, and neaps rise at the various places in Thai waters.

Table 2.

Average mean sea level of some tidal stations (approx. 5 years).

Place	M.S.L.	Springs rise	Neaps rise
1) Pattani	23.97 dms.	17.2 dms.	15.6 dms.
2) Song Khla	25.00 dms.	14.0 dms.	11.1 dms.
3) Prachuap K.	25.19 dms.	19.0 dms.	12.0 dms.
4) Bangkok Bar	25.71 dms.	32.0 dms.	28.0 dms.
5) Ko Sichang	25.53 dms.	26.0 dms.	18.0 dms.
6) Sattahib	24.15 dms.	27.5 dms.	13.5 dms.
7) Phuket	21.72 dms.	—	—

Figure 3 shows the shapes of mean sea level at different places: Bangkok Bar, Sattahib, Prachuap Khirikhan and Phuket, each with somewhat different characteristics. The first three places are of the same type as they are in the Gulf, but the last is different, as it is on open sea and follows the oceanic pattern.

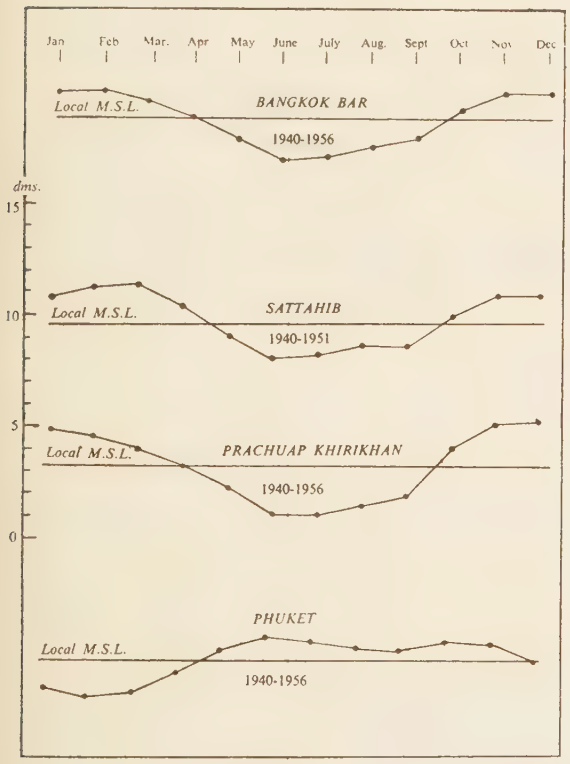


Fig. 3.—Annual variations in mean sea level along the coast of Thai waters.

The precise levelling operation was carried out by the Royal Survey Department of the Thai Army. Mean sea level did not correspond with standard level. The mean sea level at Prachuap Khirikhan has been found to be generally higher than along the west coast of the Malay Peninsula.

A difference in mean sea level from the observations at Phuket was found to be about 0.3 m. lower than at Prachuap Khirikhan. We can hardly explain why it is so, but believe that this level is not suitable for comparison with problems regarding the upheaval or subsidence of the land.

VARIATIONS IN MEAN SEA LEVEL

Variations in mean sea level from day to day resulting from long period tidal forces are relatively small. Far greater variations are brought about by the response of the waters to changes in wind and weather.

If we apply the gradient equation for the two places, Prachuap Khirikhan and Khlong Yai, then we have $\tan \Theta = \dfrac{2wu \sin \phi}{g}$

where $2wu \sin \phi$ is the horizontal geostrophic acceleration, and ϕ is positive in the Northern Hemisphere, where geostrophic acceleration is to the lefthand side. Allowing for geostrophic effects, sea level rises to the right of current.

We take $u = 100$ cm/sec, $\phi = 11° 48'$N.
$g = 981$ cm/sec^2, $w = 7.293 \times 10^{-5}$ rad/sec

As the current flows in clockwise direction, the sea level at Khlong Yai is higher than at Prachuap by $H = d \tan \Theta$, where $d = 329$ Km.

$$\therefore \quad H = \frac{329 \times 1000 \times 2 \times 7.293 \times 10^{-5} \times 100 \times 0.2048}{981}$$

$= 1.002$ m.

Hence difference of level = 1.002 m.

At Prachuap Khirikhan we find Seiche effects, a secondary effect of atmospheric disturbances, i.e., free oscillations are set up in the Gulf. The theory of standing oscillations is possible with period depending upon the dimension of the basin.

Free oscillations which occur along the Gulf quickly lose energy by radiation into the ocean, but those across the Gulf may continue to be reflected backwards and forwards for a comparatively long time until the energy of the motion is dissipated by frictional forces.

The theorem $1 = \frac{1}{2} T \sqrt{gh}$, applied to the Gulf indicates that in any semi-enclosed area there will be local oscillations.

Fig. 4.—A Seiche motion superimposed on tidal oscillation at Prachuap Khirikhan, January 2 to 3, 1955.

Figure 4 shows a Seiche motion recorded by a tide gauge at Prachuap Khirikhan.

We have $T = 40$ mins.

$g = 9.81$ m/sec^2

$h = 40$ m. (approx.)

then $$1 = \frac{\frac{1}{2} \times 40 \times 60 \sqrt{9.81 \times 40}}{1000} = 23.8 \text{ km.}$$

This figure does not show an appreciable result, however, we are still waiting for data from further examination.

DISCUSSION

K. HIDAKA: For how many places are tides predicted?

P. PUKASAB: The entire Gulf.

M.M. Eyries suggested that the resonance period of Gulf be calculated.

K. Hidaka suggested that the Gulf of Thailand might be very suitable for application of Defant's method. See *Gezeiten probleme in Landnöhe.*

PRELIMINARY STUDY OF DISCOLORATION OF SEA WATER IN THE GULF OF THAILAND

LT. COMDR. SWARNG CHARERNPHOL, R.T.N.

Hydrographic Department, Royal Thai Navy, Thonburi, Thailand.

Among natural phenomena that take place in the vast sea, discoloration of sea water is one which can be easily observed and is most important in studying the life cycle in the sea. This phenomenon can often be found in every region of the world. An observer may notice some unexpected richness, quality, or distinct color. This is called "discoloration." Discolorations differ somewhat in shade according to the intensity of light, amount of clouds, movement of the mass of the water, depth of the water, position of the observer, density of the coloring materials, etc.

Many progressive studies about discolorations have been made. Reports of discolored water in the world are shown in Table 1.

In the Gulf of Thailand, discoloration of sea water can be seen on the east and west coasts every year, and also along the east coast of the Malay Peninsula. In Thailand most of the people, even the fishermen, who have seen this phenomenon do not know the cause. They usually refer to it as "whale dung."

During the course of oceanographic surveys made in 1956 and 1957, discoloration of sea water was observed on various occasions at different locations as shown in Table 2.

LOCATION AND APPEARANCE OF DISCOLORATION OF SEA WATER

In the Gulf of Thailand, discoloration of sea water mostly occurs in the coastal area, usually within two to forty miles from the shore. Two types have been observed: it occurred in the inshore area and moved offshore; it occurred in the offshore area and moved inshore.

It seems that these two types occurred under the same conditions, but they were driven by tidal currents, by winds, or by both. They usually appear in areas in the vicinities of small bays, inlets, and estuarine areas where fresh water is flowing into the sea. They are frequently seen on the west coast of the Gulf of Thailand and especially around Chum Phon.

SEASONAL APPEARANCE

Around the west coast of the Gulf of Thailand, discoloration of sea water can be expected during the months of April to August, but in the upper part of the Gulf they can be found in March. This period corresponds to our summer and rainy season. In April, it is still very warm, and it is a transitional month during which the wind is always shifting from south to southwest. In May, the southwest monsoon starts and brings rains from the Indian Ocean. Fresh water runoffs from the west coast of the Gulf, as a result of the rainfall, contain many dissolved inorganic salts such as nitrates, phosphates, etc., which fertilize the planktons. With high temperature, calm sea, and weak current, the marine pinotial gelata bloom rapidly and caused a red tide or discoloration in a short period. There is no doubt that the seed of red tide planktons floats up and down in the Gulf all year round, but the environments do not permit a rapid growth—which causes discoloration of water.

SPECIES AND CONDITION OF DISCOLORATION OF WATER

The species of red tide planktons in the Gulf of Thailand are the same as those of other tropical seas: the blue green alga of the tropical sea, the "Noctiluca," the illuminator of the night, and one other. Fishermen report that they always appear in a big area along the coastal line and change the color of the sea to reddish, and many fish are killed. Owing to limited facilities, we have had no opportunity to study them closely. Table 2 shows the species of red tide planktons and the area in which the discoloration occurred.

Trichodesmium. The blue-green alga, which can be found everywhere in tropical seas, is very common. It is found the year round on the surface of the sea as a vast sheet, sometimes covering more than 1,000 square miles in the short time of blooming. The color of the sea is changed to brown or dirty yellow. It takes place in an area

Table 1.
Reports on discoloration of water in various regions.

Month, Year of Discoloration	Plankton Sp.	Authority of Initial Report	Location	Damage
1820	Diatoms	Scoresby, W.	Northern North Sea	Unknown
1832	*Trichodesmium* Sp.	Darwin, C.	Off Chile	,,
1858	*Peridinium sanguineum*	Carter, H.J.	Gulf of Bombay	,,
1890	Unknown	Agassiz, A.	Florida, U.S.A.	,,
1891	*Glenodinium rubrum*	White, L.	New South Wales	,,
VII-IX, 1898	*Peridinium* Sp.	Made, A.	Narangasett Bay, U.S.A.	,,
VII, 1899	*Noctiluca scintillans*	Nishikawa, T.	Shizuoka, Japan	,,
VIII, 1899	*Gonyaulax polygramina*	,,	Toba, Japan	,,
IX, 1900	*Gonyaulax polygramina*	,,	Ago Bay, Japan	,,
XI, 1900	*Gonyaulax, Ceratium*	Miye, Fish Exp. St.	Ise Bay, Japan	Pearl Oyster
V, 1901	*Noctiluca scintillans*	Nishikawa, T.	Uwajima, Japan	Unknown
VII, 1902	*Gonyaulax* Sp.	Torrey, H.B.	California U.S.A.	,,
IX, 1903	*Gymnodinium, Chaetoceros*	Miye, Fish Exp. St.	Ago Bay, Japan	,,
XII, 1904	*Gymnodinium, Gonyaulax*	Miye, Fish Exp. St.	Gokusho Bay, Japan	,,
II, 1905	*Ceratium furca*	,,	,,	,,
V, 1905	*Perdinium, Chaetoceros*	Cori, C.J.	Trieste Bay, Italy	,,
VII-VIII, 1905	40 spp. Diatoms, 6 spp. Dinoflagellates	Forti, A.	Italy	,,
VIII, 1906	*Trichodesmium erythraeum*	Okamora, K.	Off Kochi, Japan	Unknown
VI, 1907	*Polykrikos*	Asakura, K.	Off Yokohama, Japan	,,
VI, 1909	*Polykrikos*	,,	,,	,,
V, 1911	*Noctiluca*	Asakura, K.	Off Yokohama, Japan	,,
V, 1914	,,	,,	,,	None
I-II, 1917	*Dinoflagellata*	Hornell, J.	Near Madras, India	Unknown
1921	*Gymnodinium flavum*	Kofoid, C.A.	Unknown	,,
IV, 1924	*Phaeocystis pouchetii*	Savage, R.E.	California, U.S.A.	,,
IV, 1926	,,	,,	Southern North Sea	,,
XI, 1927	,,	,,	,,	,,
V-VIII, 1932	,,	Savage, Nelson	,,	,,
VIII, 1932	*Cyclotrichuim meunieri*	Powers, H.	Gulf of Maine, U.S.A.	,,
VIII, 1933	*Clathrocystis aeruginosa*	Kurashige, E.	Shizuoka, Japan	,,
V, 1933	*Peridinium*	Allen, W.E.	La Jolla, U.S.A.	Fish, Benthos
X, 1934	*Chaetoceros*	Copenhagen, W.J.	Table Bay, South Afr.	Unknown
VII, 1937	*Ceratium forca*	Ishiyanagi, S.	Tokyo Bay, Japan	,,
X, 1939	*Mesodinium rubrum*	Haneda, R.	Akkeshi Bay, Japan	,,
X, 1943	*Chaetoceros, Bacteriastrum*	Saheki, A. and Yasuda, J.	Atsumi Bay, Japan	,,
1945	*Gonyaulax polyedra, Prorocentrum micans*	Allen, W.E.	La Jolla Bay, U.S.A.	,,
XI, 1946	*Gymnodinium breauis*	Conter, G.H.	Florida, U.S.A.	Mullet, Shrimp
VII, 1947	*Dictyocha fibuca*	Tsajita, T.	Omura Bay, Japan	,,
IV, 1948	*Noctiluca scintillans*	,,	Off Goto Is., Japan	,,
1948	*Euaknoid*	Jacobs, P.K.	Off Bombay, India	,,
1948	*Aulacodiscus kittoni*	Galtsoff, P.K.	Copalis Beach, Washington, U.S.A.	,,
I, 1947	*Rhizosalenia styliformis*	Tsajita, T.	Omura Bay, Japan	,,
VIII, 1951	*Gonyaulax monilata*	Howell, J.	Florida Coast, U.S.A.	Fish, Benthos
VI, 1952	*Mesodinium pulex*	U.S. Fish and Wildlife vessel *Alaska*	Lat. 28° 30′ N., long. 84° 30′ E.	,,

within 50 miles from shore. The first stage of blooming occurs when the organisms spread all over the sea; they are light brown or light yellow. At the full stage of blooming, the color changes to yellow, dark yellow, and finally to dirty yellow. An oily smell is noticeable. Samples taken by bucket were put in glass jars, and after a few minutes the organisms floated up to the surface of the glass. After about two hours, the liquid underneath changed to light red and then to medium red. When the organisms at the surface of the glass are exposed to the air, they become dark red; and the smell increases.

The number of the cells in the concentrated area was reported as more than 1,000,000 per one cubic meter of sea water; the number declined in deep water more or less in the same way as *Trichodesmium*, with very few at the bottom. At night this species of plankton looked like little glittering stars in the dark sky. When we put some cells in a glass jar, all of them floated up to the surface very rapidly. There was only a faint odor like fresh vegetables.

Unknown sp. This species of plankton caused great damage to marine life, especially the Benthos, because they could not move away from the

Table 2.
Location of discoloration of water in the Gulf of Thailand.

No.	Species	Color	Location	Season	Area covered (sq. miles)	Damage
1.	*Trichodesmium*	yellow-brown	Upper part, east and west coast	March to August	10-2,000	Unknown
2.	*Noctiluca*	green, bright green	Upper part, east and west coast	May to August	1-500	Unknown
3.	Unknown	reddish	Upper part, Chum Phon	June to August	5-500	Fishes, Benthos.

More than 1,000,000 cells per one cubic meter of sea water have been reported in the concentrated area of blooming. However, the number decreases as the depth of the water increases. In normal conditions, we found that the organism concentrated on the surface and decreased continuously to about one-fourth of the depth of the area.

When the organisms died, the smell increased and the color of the water changed to dirty yellow, with an oily, jelly-like matter on top. It drifted to the beach and darkened in the hot sun; the smell lasted for a few days.

Noctiluca. The blooming of this type of plankton occurred a month or two later than the blooming of *Trichodesmium* sp., and the location was usually not more than 10 miles from shore. At the first stage of blooming, the color was very light green. Later on it changed to medium and dark green and the observers could see them very clearly from a distance of about one mile. area of blooming. Sometimes fish were driven from the area of this red tide and went into fishing stakes and also onto the beach. A great number of sea eels, shrimp, and slip mouth were driven up. The color of the sea water in the discoloration area was light red to purple. The cause might be a species of Dinoflagellate, *Gonyaulax*. The temperature of the sea water at the concentrated area was about one to two degrees C. higher than usual.

RELATIONSHIP BETWEEN DISCOLORATION OF SEA WATER AND THE WEATHER

Almost all of the blooming of plankton in the Gulf of Thailand took place after the first rains of the southwest monsoon, which influences the climate over Thailand in the early part of March. The seeds of red tide plankton are distributed in every square mile of the sea. When stimulated by mineral salts from the rain water with a calm sea and high temperature, they start blooming.

Map 1.

Map 1.— Locality of Discoloration of water in the Gulf of Thailand.

THE DAMAGE OF MARINE LIFE BY DISCOLORATION OF WATER

In the season of the red tide, we know that many species of important marine life are killed on the east and west coasts of the Gulf yearly. We do not know the actual number of tons of fishes or Benthos which are killed by this phenomenon. This remains to be investigated.

DISCUSSION

A.F. BRUUN: This study, and others of its type, are important to productivity. I hope that work along these lines will continue.

THAM AH KOW: *Trichodesmium* is also found in Singapore Straits during July and August every year. Bands of this algae can be observed in the Java Sea and between northern Australia and Java during January and February. Have the organisms causing red water been identified?

S. CHARERNPHOL: No.

THAM AH KOW: Because of the toxic effect on fishes, the reddish color mentioned in the paper is probably due to *Gymnodinium*, which was also found off the eastern coast of Australia in 1947.

THE EFFECTS OF THE WARM AND COLD CURRENTS IN THE SOUTHWEST PACIFIC ON THE GROWTH RATE OF REEF CORALS†

TING YING H. MA

National Taiwan University, Taipei, Taiwan.

(Abstract)

The China coast cold current occurring only in winter from Gulf of Peichihli to the South China Sea not only narrows the distribution of reef corals to 24°N., but also has a clear effect on the annual growth values of reef corals at lower latitudes. In winter this current washes the China coast and affects west coast of Taiwan, but the east coast of Taiwan belongs to the region of the warm Kuroshio current from the south. This contrast is clearly reflected in the difference in annual growth values of reef corals. For the same species of reef corals the annual growth value around the Pescadores is much less than off the east coast of Taiwan at Suao and around the Lanshu Island. The effect of the China coast cold current is recognizable as far south as Pratus Island.

DISCUSSION

R.R. HARRY-ROFEN: Examination of corals on ships recently sunk show the "rings" or "ridges" could not be annular, i.e., in many cases there were too many of them. How do you explain this?

T.Y.H. MA: The annular rings or ridges are clearly marked in the subtropics, where seasonal changes in the environment are large, but not clearly marked in the tropics proper. One must study the details of the annual growth pattern very carefully in order to interpret ridges or rings in terms of annual growth. I have compared my figures with those obtained from cultural experiments.

† Published in *Oceanographia Sinica* **5** (2), 1957.

A PRELIMINARY STUDY OF THE SEA TURTLES IN THE GULF OF THAILAND†

COMDR. A. PENYAPOL, R.T.N.

Hydrographic Department, Royal Thai Navy, Thonburi, Thailand.

(Abstract)

A preliminary study of the Green turtles *(Chelonia mydas)* and the Hawksbills *(Erethmochelys imbricata)* at Ko Khram and Ko Kra during the year 1956-57, their breeding, embryological development and their distribution in the Gulf of Thailand.

DISCUSSION

D.V. BAL: Are there other places where turtles are found, besides the main two places you have discussed?

A. PENYAPOL: Yes, generally along the coast, but in smaller numbers.

D.V. BAL: The same species?

A. PENYAPOL: Yes, there are only two species in the Gulf.

M.-H. SACHET: In the Cook Islands, turtles are raised successfully on a limited scale.

D.V. BAL: Has a systematic survey of turtles been done?

A. PENYAPOL: Observations are being made and compiled with the object of accomplishing this.

† Published in *Siam Soc. Nat. Hist. Bull.* **17**: 23, 1958.

NESTING POPULATIONS OF SEA TURTLES ON THE EAST COAST OF MALAYA†

JOHN R. HENDRICKSON and ERIC R. ALFRED

Zoology Department, University of Malaya, Singapore. Curator of Zoology, Raffles Museum, Singapore.

(Abstract)

In Malaya, as in many other parts of the world, the eggs of sea turtles are sought after for food. They are collected almost everywhere sea turtles nest in any numbers, and they find a ready market at all times. It is estimated that roughly two million eggs, constituting something over fifty tons of high grade protein food, are consumed each year in Malaya. There is reason for considerable interest in the local breeding populations of sea turtles and for giving thought to their proper management in order to ensure continuance of this protein resource.

Basic to any management program, of course, is information on just what there is to be managed. For wild populations of sea turtles, such information may not be easy to obtain, particularly as regards quantitative data. Owing to a combination of circumstances which is apparently almost peculiar to Malaya, it has been possible to obtain information not only on the qualitative aspects of our management problem (the different species nesting and their relative proportions up and down the coast), but also on its quantitative aspects. This paper consists principally of the writers' estimate of the situation in Malaya, the structure on which future management programs can be based. While the assumptions necessary for the estimates to be presented have been made with all possible caution and are based on the best information obtainable at the present time, it must be stressed that the writers are fully conscious of the possibility of error and that they hope the figures will be accepted for no more than what they are intended to be—interesting first approximations to the actual facts.

DISCUSSIONS‡

(Oceanography Section)

THAM AH KOW: The taking of eggs along the east coast of Johore, a state in Malaya, is prohibited and that in itself will be a measure of conservation.

L.D. BRONGERSMA: Studies of systematics and distributions of turtles should be made. Poisoning sometimes occurs.

M.-H. SACHET: The Pacific Science Board (U.S. National Research Council) has attempted to maintain an interest in the study of turtles. Perhaps a formal recommendation could be made by the Congress, and then the Board would be more able to aid in organizing further research.

THAM AH KOW: In Malaya the taking of turtles is forbidden by law. However, it would be opportune to start a tagging program in order to ascertain the growth rate and other biological characteristics of the turtles including egg laying.

A.F. BRUUN: Tagging should be done in various breeding areas. Caution should be used in taking eggs in a confined breeding area such as those in the Gulf of Thailand.

(Zoology Section)

H.J. COOLIDGE: This is an interesting study which reveals that the turtles delay returning to these laying beaches.

E.R. ALFRED: Tagging shows a three-year cycle.

H.J. COOLIDGE: By keeping turtles in a "hatchery" for several months, it should be possible to increase numbers greatly. Hendrickson thinks protection for this early period would give a 50 per cent increase in population.

E.R. ALFRED: I would like to see some eggs kept for hatchery purposes. But we do not know whether turtles return to the same beach. Hence, if we conserve from only a few beaches, some turtles would eventually lose their populations from complete egg harvest for food.

H.J. COOLIDGE: This turtle research is long overdue, but we hope it will be increased in Southeast Asia.

† Published in *Raffles Museum Bulletin* **29**. 1958, with the consent of the Organizing Committee of the Ninth Pacific Science Congress.

‡ This paper was presented in Oceanography Section as well as in Zoology Section, therefore both discussions thereon are given here. — *Editor*

V.V. SUPACHAI: Could you give a resumé of Commander Amporn's report?

E.R. ALFRED: He conducted some researches on embryology, breeding habits and census studies, and plans to undertake tagging studies.

V.V. SUPACHAI: It is possible that Mr. Alfred's tagged turtle may come to breed on Thai shores.

A.G. SEARLE: Did you tag in several places?

E.R. ALFRED: Yes, and we noticed most turtles showed "homing" behaviour within a single year's activity.

J.L. HARRISON: Can you hazard guesses as to whether there may be places where there is less than 100 per cent collection of turtle eggs?

E.R. ALFRED: There probably are a number of such places. In Johore, where it is illegal, I know eggs are collected.

L.D. BRONGERSMA: We still do not know how many species of turtles there are. There may be differences between Atlantic and Pacific, and even east and west Pacific forms. Further taxonomic studies are indicated.

H.J. COOLIDGE: Dr. Hendrickson's study should soon be published.

E.H. TAYLOR: Does Mr. Carr confine his works to the Caribbean?

H.J. COOLIDGE: He feels he has a focal nesting area, and if these could be protected, the population of the Caribbean could be maintained.

E.H. TAYLOR: Do these Indo-Pacific turtles migrate as do the Caribbean forms?

H.J. COOLIDGE: We should have international cooperation on tag returns. Tags should indicate their source.

A.R. MEAD: Tags should indicate source in several languages.

J.L. HARRISON: I would suggest a reward for the return of tags.

Symposium: *Disposal of Radioactive Waste*

A METHOD OF MEASUREMENT OF RADIOACTIVITY IN SEA WATER

Y. MIYAKE and Y. SUGIURA

Geochemical Laboratory, Meteorological Research Institute, Mabashi, Suginami, Tokyo, Japan.

To measure the gross radioactivity of fission product in sea water, one has to use the co-precipitation method by adding appropriate carriers to separate the active substance from the larger amount of saline matter. Calcium carbonate, calcium phosphate, and a mixture of barium sulfate and iron hydroxide are often used as carriers. The use of the last of these was proposed by the authors in 1954. The comparison of the efficiency of collection of fission product from sea water was made with regard to three different carriers above mentioned. The result of comparison is given in Table 1.

Table 1.

Comparison in the efficiency of co-precipitation of fission product from sea water.

Scavenger	Amount of precipitate in mg.	Efficiency of collection in %
$Fe(OH)_3+BaSO_4$	35	85
$CaCO_3$	35	77
$Ca_3(PO_4)_2$	35	64

The composition of the above fission product put into sea water was determined by separating each nuclide with the ion exchanging resin (Amberlite IRA-120). The result of analysis showed that the sample of fission product consisted of 9% of anion, 1% of Zr and Nb, 80% of rare-earth and 10% of alkali-earth elements. The efficiency of co-precipitation of each radio-nuclide group with 35 mg. of mixed scavenger per litre of barium sulfate and iron hydroxide was determined. The results are shown in Table 2.

As can be seen, the efficiency of anion and alkali-earth elements is low. This is partly because of the older age of the fission product (about 2 years) and because most of the alkali-earth consists of radio-strontium. Since the solubility of strontium sulfate is comparatively high, and natural strontium contained in sea water may act as a hold-back carrier, $BaSO_4$ may not be a good scavenger for strontium. It is known that strontium in sea water can be almost completely co-precipitated with calcium carbonate. However, since a considerable amount of calcium is contained in sea water, the volume of the precipitate becomes greater and this produces an unfavorable increase of self-absorption. To lower the solubility of strontium sulfate, some ethyl alcohol and 20 mg. of strontium and 10 mg. of barium were added to sea water. By this procedure, the co-precipitating efficiency of strontium was increased up to 93%. However, some magnesium hydroxide is also precipitated by the addition of alcohol which brings about the lowering of counting efficiency again.

Table 2.

The efficiency of co-precipitation of each nuclide group.

	Percentage of co-precipitation
Anion	43
Zr and Nb	91
Rare-earths	99
Alkali-earths	28

Next, the effect of the relative amount of carrier to that of sea water is examined. The result is given in Table 3 which shows the remarkable increase of efficiency when the relative amount of carrier increases.

Table 3.

The relation between the co-precipitation efficiency and the relative amount of scavenger to sea water.

	The amount of sea water per each 10 mg. of Ba and Fe	Efficiency of collection in %
1	1000 ml.	85
2	50	91
3	10	99

Based on the above results, the next procedure was obtained. To one litre of sea water 10 mg. of iron as iron alum is added. Iron hydroxide and calcium carbonate are precipitated by adding ammonia, ammonium chloride, and ammonium hydroxide which are separated with centrifuge from sea water. The precipitate is dissolved with 10 ml. of HCl (1:1); then 10 mg. of barium as barium chloride is added; and the precipitate of barium sulfate and iron hydroxide are formed by adding sodium sulfate, ammonium chloride, and ammonia. The activity of the precipitate is measured after drying. The result gives about 90% efficiency on an average which is a little higher than the original method.

REFERENCES

Miyake, Y., Sugiura, Y. and Kameda, K., 1955, On the Distribution of Radioactivity in the Sea Around Bikini Atoll in June, 1954. *Papers in Meteorology and Geophysics*, **5**: 253 - 263.

Health and Safety Laboratory, 1956, *Operation Troll*, NYO 4656 (Health and Biology), US Atomic Energy Commission.

A MEASURE ON LEVEL OF STRONTIUM-90 CONCENTRATION IN SEA WATER AROUND JAPAN, AT THE END OF 1956

YOSHIO HIYAMA and RYUSHI ICHIKAWA

Fisheries Institute, Faculty of Agriculture, University of Tokyo, Tokyo, Japan.

INTRODUCTION

The present level of concentration of strontium-90 (Sr^{90}) in oceanic water, caused by fall-out of fission products by nuclear weapon tests, makes it necessary to collect a huge amount of sea water to measure its concentration by chemical analysis and by radio-assay. Thus, few reliable data on it are available to oceanographers at present, as well as little information on the proper amount of sea water to be sampled.

The authors tried a rough measurement of the level of Sr^{90} concentration of oceanic water based upon its concentration in calcareous tissue, bone and shell, of marine organisms, by Hiyama's idea *(3,4,5)* that the ratio of isotopic dilution is the same in organisms as in their environmental water, after the equilibrium.

CONSTANTS ON STRONTIUM CONCENTRATION

The figure for the concentration of stable strontium in oceanic water is rather constant and is 7 mg. (metal) per liter as measured by Thompson and Chow *(10)* and by Sugawara *(9)*, where there is 0.4 g. (metal) of calcium per liter. Many data on concentration of stable strontium in marine organisms were obtained by Asari with precipitation method *(1)*, by Thompson and Chow with flame-photometer *(10)*, and by others, especially with regards to strontium-calcium ratio. Here 7 mg. per liter was used for the stable strontium concentration of oceanic water as the basis of the calculation.

Sr^{90} CONCENTRATION IN FISH BONE

During December of 1956, fishes were collected from the Central Fish Market in Tokyo with some notes on the fishing ground where caught. About 100 - 200 g. of dried bone of each sample were chemically analyzed by Dr. Tamiya Asari, Mr. Morito Chiba, and Mr. Tadashi Ariki of the laboratory of the Japan Inspection Company for the amount of stable strontium by Asari's precipitation method *(2)*, and radio-assayed by Dr. Fumio Yamasaki and Mr. Akira Hashizume of the Science Research Institute for the amount of Sr^{90} as shown in Table 1.

Table 1.

Fish name	Locality caught. (Approx. depth)	Sr^{90} μμc per 1 g. of Ca in fish bone	Sr^{90} μμc per 7mg. of Sr in fish bone	Sr^{90} μμc per litre of sea water
Croaker (*Sciaena* Sp.)	East China Sea (50 m.)	0.11 ± 0.078	0.1	0.1
Horse mackerel (*Trachurus japonicus*)	Japan Sea, off Shimane, (5 m.)	0.38 ± 0.04	0.64	0.64
Alaskan polluk (*Theragra chalcogramma*)	North Pacific, off Hokkaido, (15 m.)	0.19 ± 0.080	0.23	0.23
Spiny eel (*Dinoguellus grigorejewi*)	North Pacific off Hokkaido, (50 m.)	0.028 ± 0.028	0.03	0.03
Blue Shark (*Goleus glaucus*)	Mid Pacific, (Surface)	0.72 ± 0.10	8.4	8.4

As is reported in the author's previous papers *(3,5)*, the Sr^{90} concentration in isotopic dilution ratio to the stable strontium, "moonlight" unit (μμc/7 mg. of stable strontium), in fish body must be the same as in environmental water, when the entire uptake is completed or the equilibrium is established.

In this case, no information on the degree of uptake is available. However, the figures of the moonlight concentration *(3, 4)* of calcareous tissue should be interpreted as the figure of the concentration of environmental water in μμc/l. where the fish had lived since they were born as an overall figure. Actually the contamination of fish is caused partly by uptake directly through epithelium from environmental water, and partly indirectly by intake of contaminated food organisms. In both procedures, the isotopic dilution ratio must be the same.

FALLOUT DILUTION BY DEPTH

By Table 1, the Sr^{90} concentration of water is somewhat related to the depth of the ocean inhabited by these fish.

These concentrations were checked against the amount of fallout on the area around Japan at the time they were grown. The cumulative globe's surface deposit at the end of 1956 around Japan calculated by Hiyama *(4)* is about the same as by Miyake *(7)* and is bout 6 mc/km² or 6 mμc/m². As the fishes are two or three years old, half of that figure would be adequate for the period in which they grew up. Since the amount of Sr^{90} fallen on the surface of the ocean would be diluted by the amount of water down to the depth of *A* meters, the Sr^{90} concentration in sea water must be $6/A$ μμc per liter. As expressed in Fig. 1, both the calculated (in black bar) and measured (point at front of fish) figure is almost coincidental, though for the two deeper inhabitants we have no accurate figure.

REQUIRED AMOUNT OF SAMPLE

If the efficiency of a Geiger-Muller counter requires 200 dpm. in order to get accurate figures of one order, minima of about 100 liters of surface water and about 1,000 liters of deeper (around 50 meter depth) water is required for the situation recently found in the North Pacific. However, by a kind of bio-assay as above mentioned, the separation of strontium from calcium by a precipitation as in Dr. Asari's method, and the radio-assay, only about 100 g. of calcium from fish bone is enough to get stable strontium amount with the same degree of accuracy and to get 200 dpm. for radio-assay, except for the deep sea inhabitants, at the present level of contamination. (Ca is about 1/3 of ash in fish bone.)

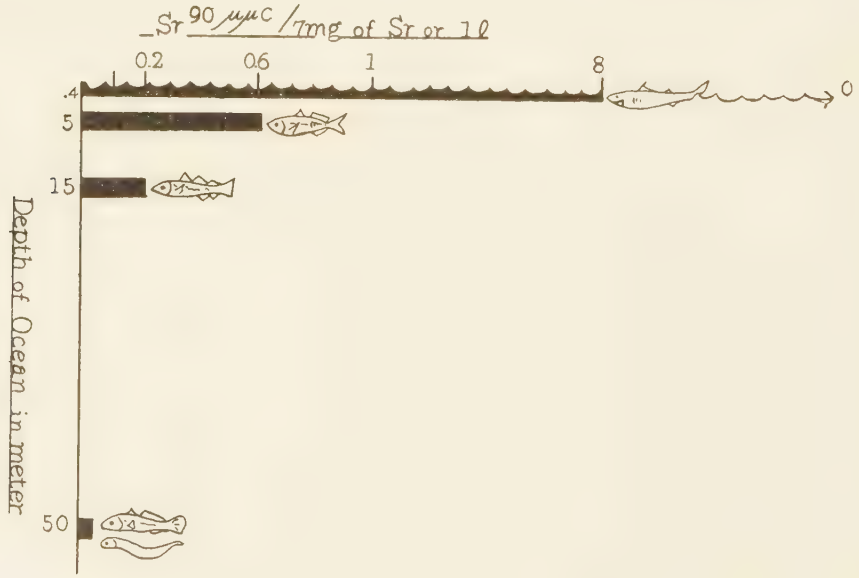


Fig. 1.—

FALLOUT ACCUMULATION IN SEA WATER

About one to five hundred grams of clam shell *(Paphia philippinarum)* collected from two localities, one at shore close to a small river mouth and the other offshore near the Fisheries Laboratory of the University of Tokyo, at Ikawazu, Aichi Prefecture, in three succeeding winters (1954 to 1956) was chemically analyzed by Dr. Asari's Laboratory and radio-assayed by Dr. Yamasaki's Laboratory as mentioned before. Three other samples of the same shell from Tokyo Bay were also measured in the same way.

As shown in Table 2, the Sr^{90} concentration in ratio to the stable strontium in the shell from inshore and offshore points at Ikawazu is not significant, but somewhat higher than in Tokyo Bay. Fig. 2 expresses the increase of the concentration in comparison with that of calculated accumulated Sr^{90} on the globe's surface *(7)*.

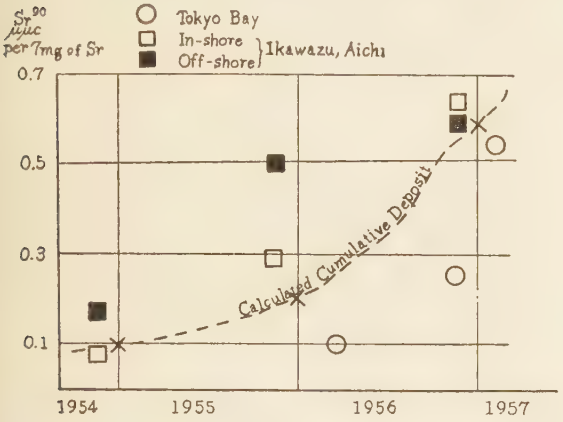


Fig. 2.—

In comparing the moonlight concentration of Sr^{90} in shell to the cumulative surface deposit of respective year, the depth of the water to dilute the fallout is about 10 meters (the graph of cumulative ground deposit is plotted by that dilution), if we neglect the influence of flow-out of the river water. As this shell fish actually lives in a zone of this depth or a little less, the figures here used would not be inapplicable.

FLOW-OUT INFLUENCE IN THE PACIFIC

The data described above are not adequate to indicate the effect of river water on the Sr^{90} concentration of coastal water.

In previous sections, the author assumed a homogeneous distribution of Sr^{90} by fallout. However, though the waste from industrial pile might not have influence upon Pacific waters yet, some effect of flow-out from the Marshall Islands in the South Pacific mainly caused by the test firing of nuclear weapons was found during 1954.

The *Shunkotsu Maru* survey a few months after the 1954 detonation, found a clear pattern of flow-out of fission products from the target area *(6)*, but the pattern had almost faded away or scattered widely in the Pacific due to flow and dilution when Japanese and U.S. boats surveyed

Table 2.

Locality	Date of Collection	Ca % in shell	Sr/1000 Ca	Sr^{90} μμc per 1 g. of Ca	Sr^{90} μμc per 7mg. of Sr
Tokyo Bay	1956 Feb.-Apr.	38.5	2.9	0.04 ±0.02	0.1
,, ,,	1956 Dec.	38.5	2.9	0.098±0.02	0.24
,, ,,	1957 Apr.	38.2	3.0	0.23 ±0.03	0.53
Ikawazu in shore	1954 Nov.	38.5	2.9	0.03 ±0.03	0.07
,, ,,	1955 Nov.	38.5	2.9	0.14 ±0.05	0.27
,, ,,	1956 Dec.	38.4	3.3	0.31 ±0.02	0.64
Ikawazu off shore	1954 Nov.	38.2	2.9	0.08 ±0.02	0.18
,, ,,	1955 Nov.	38.2	3.3	0.24 ±0.03	0.50
,, ,,	1956 Dec.	38.1	3.5	0.31 ±0.03	0.59

several months later. During these surveys, no Sr^{90} concentration data was obtained on both sea water and the organisms.

However, the *Shunkotsu Maru* brought back 25 specimens of vertebra bones and caudal fins of tuna-like fishes from her second survey in 1956 by request of the author, and the stable strontium was chemical analyzed by Mr. Chiba and radio-assayed by Mr. Ichikawa as already reported *(6)*. Among most of the 25 specimens, the moonlight Sr^{90} concentration in bone and fin was below the detectable level (5 μμc/7 mg. of Sr in this survey), but 6 specimens showed 7.5 to 24 μμc/7 mg. of Sr, and the highest was 159 in a large specimen of Black Marlin.

By an approximate measure of the ratio of Sr^{89} to Sr^{90} in this bone, it appears that the Sr^{90} of this specimen originated largely from the test of 1954.

This indicates that the environmental water which this fish had inhabited averaged 169 μμc per liter in Sr^{90} concentration during the period the fish grew, without considering physical and physiological decay. Actually, as the Black Marlin was several years old, the uptake of Sr in bone from environmental Sr during two years would not be complete. So, the actual sea water concentration the fish encountered some days must have been higher than this level and it would be ten to one hundred times the level of fallout contamination. Actually, such heavy contamination of fish is caused by taking contaminated food, but the food organisms themselves must have been in equilibrium with the environmental water. High Sr^{90} concentration must have existed in the South Pacific in a small zone near the target area.

MAXIMUM PERMISSIBLE SR^{90} CONCENTRATION OF SEA

It is known that a standard man of 70 kg. weight has 1 kg. of Ca and 0.7 g. of strontium (0.016 - 0.2. av. 0.05 by Turekian and Kulp), and 0.1 μc is a maximum permissible total body burden for Sr^{90} in it. Therefore, the maximum relative concentration of Sr^{90} is either 100 μμc per 1 g. of Ca or 1,000 μμc per 7 mg. of Sr total.

The length of time for bone to come into equilibrium with food is several decades for the adult and several years for the infant, the younger the shorter. Sr^{90} decays physically 10 per cent in four years. So, if we neglect decay in considering the equilibrium, from fish to human bone, and also from sea water to human bone, as the isotopic dilution rate would not change during these biological procedures, that for sea water must be the same as that for human bone.

Then the maximum permissible concentration in sea water must be 1,000 μμc per liter, as 7 mg. (metal) per liter is a normal concentration of Sr in sea water. And, as 1 curie of Sr^{90} weighs 7 mg., in the ratio of number of atom, Sr^{90} must be 10^{-9} to total Sr.

Though the amount of Sr in bone varies greatly, this calculation is used as an average figure. Thus, for maximum value, 1/10 of this figure must be safe to use. But, on the other hand, no nation is building their bone by marine products only. Even in case of Japan, merely a half of Sr comes from aquatic products, and for most nations less than 10 per cent. This fraction should be considered for the estimation too.

SUMMARY

1. By chemical analysis and radio-assay of calcareous tissue of marine organisms, Sr^{90} concentration obtained in terms of an isotopic dilution ratio (moonlight unit) can tell the concentration in environmental water as an overall figure since the fish was born.

2. Sr^{90} concentration in bones of five kinds of fish inhabiting various depths and caught at the end of 1956 shows a reasonable value allowing for the dilution of fallout calculated for that time by the layer of water down to the depth of inhabitation.

3. To get accurate figures of one order, the concentration of sea water around Japan at the end of 1956 requires 100 l. for surface water and 1,000 l. for deep (about 50 m.) water. For the same degree of accuracy, about 100 to 1,000 g. of shell or dried fish bone can be used as the material for bio-assay.

4. Clam shell collected on the coast during the past three years had Sr^{90} concentration in a similar tendency, as the calculated cumulative deposit on the earth's surface.

5. Sr^{90} concentration of bone and fin of tuna-like fishes caught in the South Pacific showed the temporary existence of intensive flow-out from the test spot.

BIBLIOGRAPHY

(1) Asari, Tamiya, 1944, Geographical Distribution of Strontium, *Scientific Papers of Institute of Physical and Scientific Research*, **23** (403).

(2) ———, 1950, *Japanese Journal of Chemistry*, **70** and **71**.

(3) Hiyama, Yoshio, 1957a, Maximum Permissible Concentration of Sr^{90} in Foods and its Environment, *Records of Oceanographic Works in Japan*, **3** (1).

(4) ———, 1957 b, A Measure of Future Sr^{90} Level from Earth Surface to Human Bone, *Japanese Scientific Monthly*, **10** (3).

(5) ——— and Ichikawa, Ryushi, 1957, Uptake of Sr by Marine Fish from the Environment, *Rec. Oceano. W. Jap.*, **3** (1).

(6) ——— *et al.*, 1957, *Report on the Second Survey of Shunkotsu Maru*, Ministry of Public Health.

(7) Miyake, Yasuo, 1957, (in press).

(8) ——— *et al.*, 1956, *On the Distribution of the Radio-activity in the Sea around Bikini Atoll in June, 1954. Research in the Effects and Influences of the Nuclear Bomb Test Explosions*. Japan Society for the Promotion of Science, p. 953.

(9) Sugawara, Ken, n.d., (in press).

(10) Thompson T.G. and Chow, T.J., 1955, Flame Photometric Determination of Sr in Sea water, *Ann. Chem.*, **27**: 18-27.

PROCEEDINGS OF THE NINTH PACIFIC SCIENCE CONGRESS

THE METABOLISM OF RADIOSTRONTIUM BY MARINE FISHES

HOWARD BOROUGHS

University of Hawaii Marine Laboratory, Honolulu, Hawaii.

As a result of the fallout from nuclear weapon testing, the oceans of the world have become more radioactive than they have been in the past. The United Kingdom and the United States have already begun to utilize nuclear power reactors on a commercial scale, and in the very near future, many countries all over the world, including those in Southeast Asia, will be faced with the problem of the disposal of radioactive materials which are waste products of these nuclear power plants.

The increase in the number of radioactive atoms of any one element has been as yet relatively small, so far as the oceans are concerned. In other words, although a very large number of strontium-90 atoms have been added to the oceans since 1945, the percentage of radioactive to stable strontium is extremely small. This statement is certainly valid for the oceans as a whole, and even in regions where the local fallout is very high. What is important to know, therefore, is how much radioactivity is accumulated by marine organisms either in terms of microcuries or in terms of milliroentgens, so that an estimate and ultimately a knowledge of the hazard is available.

For the present, the most important consideration is how much of this introduced radioactivity is likely to be accumulated by man. This paper is concerned with the problem of how fish take up and lose radioactive strontium. In the experiments to be described, we have used strontium-89 and strontium-90, both of which have certain advantages for a particular experiment. We are currently continuing our study of strontium metabolism, particularly in food chains, with the aid of Sr^{85}. Strontium-85 has the advantage of having a gamma emitting daughter, so that the organ or organisms can be counted without tedious preparation.

The true marine fishes used include: *Euthynnus yaito* (skipjack), *Neothunnus macropterus* (yellow fin tuna), *Coryphaena hippurus* (dolphin), *Carangoides ajax* (papio), and *Kuhlia sandvicensis* (aholehole). The bulk of the work to be described, however, was carried out on the brackish water fish *Tilapia mossambica* which lives in either fresh or salt water. Although this fish is not a representative marine fish, it has certain advantages in studying ionic regulation.

Strontium-89 was fed to the large fish by incorporating a known amount of Oak Ridge isotope into gelatine capsules containing cracker crumbs. The capsule was sewn into a piece of fish muscle and tied to a thread. The muscle containing the isotope was then thrown to an individual fish. Two techniques were used with the small fish. Some were force fed gelatine capsules, others were fed by extruding a solidified gelatine solution containing the isotope directly into the stomach.

The fishes were dissected, dried, and ashed in a muffle furnace at about 600°C. The ash was spread on aluminum planchettes and counted, using end window G-M tubes and commercial scalers.

Figure 1 shows that the excretion of Sr^{89} by tuna fish is very rapid. Half of the amount ingested was gone after a few hours, and at 24 hours only one to two per cent remained. The amount that was retained at 24 hours persisted for the duration of the experiment, which lasted almost one month.

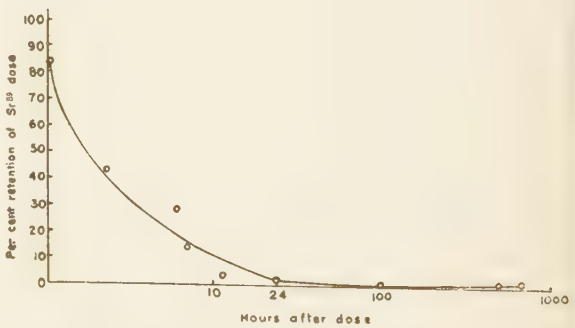


Fig.1.—The decrease of ingested Sr^{89} in pelagic fish as a function of time.

Figure 2 shows the internal distribution of Sr^{89} in tuna fish. It can be readily seen that the visceral organs eliminate this isotope extremely rapidly. The structural tissues, on the other hand, retain a more or less constant amount for the one month period. These structural tissues in-

clude the skeleton, operculum, gills, integument, and muscle. It is interesting to note that the so-called dark muscle which has a better supply of blood than does the light muscle had less radioactivity per gram ash than did the light muscle. Of the total radioactivity found in the fish after 24 hours, about 60 per cent is found in the bones, 25 per cent in the gills, 10 per cent in the integument, and 8 per cent in the muscle.

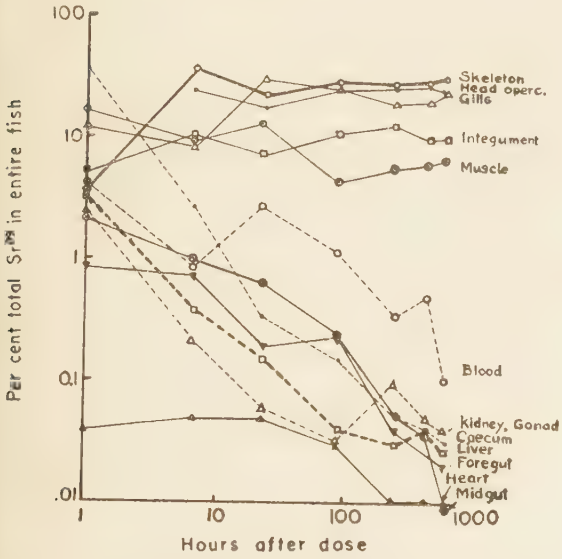


Fig. 2.—The distribution of Sr^{89} in the various organs of pelagic fish as a function of time.

Similar experiments using *Tilapia mossambica* gave results which are entirely comparable, although the rate of loss was slower. Fig. 3 shows that 50 per cent of the dose was still present at 12 hours, rather than at 2 hours, and that it required about 4 days to level off. The amount which was retained by *Tilapia* was somewhat higher than that retained by tuna. This amount varied between five and ten per cent of the dose rather than one to two per cent as was found with the tuna. This higher retention and the slower loss may be a reflection of the fact that tunas are very active fish, while *Tilapia* are typically bottom feeders and are quite sluggish.

The internal distribution of Sr^{89} in *Tilapia* is shown in Fig. 4. The retention of Sr^{89} in *Tilapia* is somewhat different from the retention in the tunas. The major amount of strontium is present in the bones, being about 65 per cent of the total recovered. However, the integument of *Tilapia* has about 25 per cent of the total, which is more than twice as much as the amount found in tuna. On the other hand, *Tilapia* gills have only about 10 per cent of the total, and the muscles retain about 2 per cent. The differences in the amounts retained is probably due to the fact that *Tilapia* have larger scales, and have more surface in terms of weight than have the larger tuna fish.

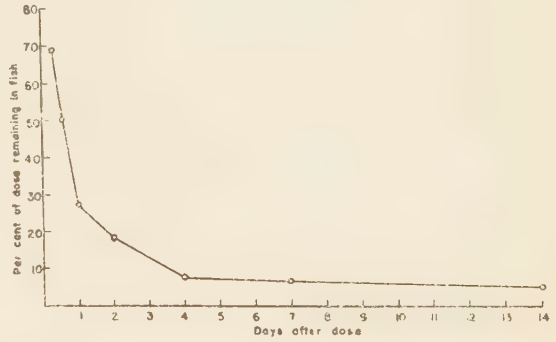


Fig. 3.—The decrease in the retention of a single ingestion of Sr^{89} by *Tilapia*.

Fig. 4.—The percentage of total Sr^{89} recovered in various tissues of *Tilapia* after a single ingestion.

We were interested in the ability of fish to take up ions directly from sea water. Almost no information on this subject is available for marine fish, although some experiments on the uptake of ions by fresh water fish have been reported.

Adult *Tilapia*, that is, fish of about 100 grams wet weight, were put into a carboy containing filtered sea water. Six fish were put in each container which held 20 liters and almost 2 millicuries of Sr^{89}. The water was aerated, but the fish were not fed for the duration of the experiment which lasted 21 days. Since the amount of Sr^{89} actually

taken up was a very small percentage of the amount present, the dose to which the fish was exposed can be considered constant.

Figure 5 shows that the initial uptake, which may be simple exchange, was very rapid, and that after about one week, the rate of accumulation of Sr^{89} was very slow. Neither the route nor the mechanism of ion uptake by fish is known, although at the Hawaii Marine Laboratory we are actively engaged in this research at present. The uptake of Sr^{89} may be by way of the gills, the epithelial tissue in the mouth, directly through the skin, or by absorption from the gut. Marine fish swallow water in order to regulate the osmotic concentration of their body fluids, but it is known from experiments carried out in the author's laboratory that cesium ions can be taken up directly through the skin. To what extent the gills or mouth epithelium can take up cations is unknown.

This figure shows that in mature fish, the concentration ratio, that is, the microcuries of Sr^{89}/gram fish divided by the microcuries of Sr^{89}/gram sea water did not reach unity in three weeks. This indicates that the net incorporation of strontium in such organs as the gills and bones is very slow in mature fish. Mature animals in general do not make bones as rapidly as do young animals, so this conclusion is hardly startling.

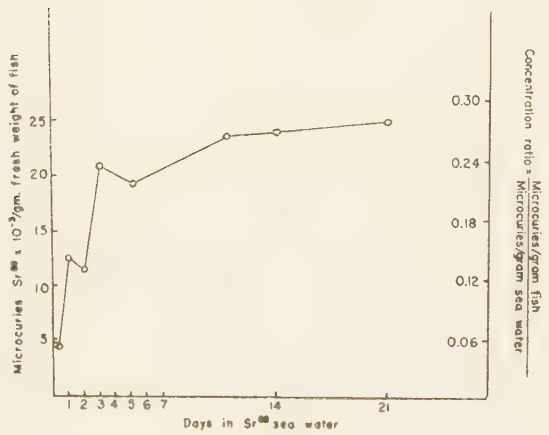

Microcuries Sr⁸⁹ x 10⁻³/gm. fresh weight of fish
Concentration ratio = Microcuries/gram fish / Microcuries/gram sea water
Days in Sr⁸⁹ sea water

Fig. 5.—The uptake of Sr^{89} in solution by *Tilapia*.

Figure 6 shows the internal distribution of Sr^{89} in these *Tilapia*. The rank order of Sr^{89} found in the *Tilapia* that were *fed* the isotope is skeleton, integument, gills, muscle, and visceral organs. The rank order of the isotope found in the tissues of the *Tilapia* which took up the isotope directly from sea water is skeleton, visceral organs, integument, gills, and muscles. The visceral organs are out of line, therefore, and because no attempt was made to analyze the individual organs, we cannot say exactly where in the viscera this strontium is to be found.

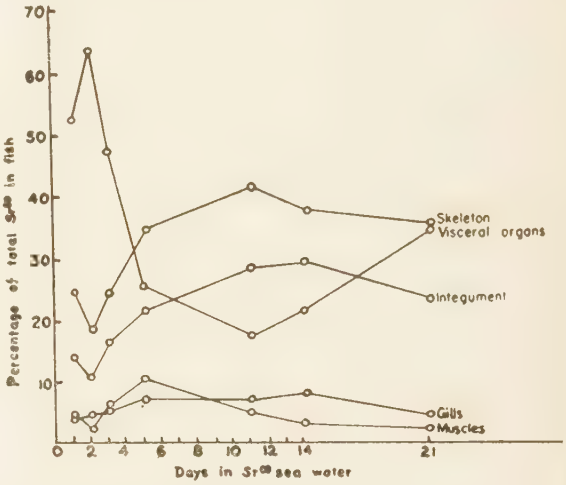


Fig. 6.—The internal distribution of Sr^{89} taken up by *Tilapia* from sea water.

Strontium-89 purchased from Oak Ridge is known to contain a small amount of Sr^{89}. As Sr^{89} has a much shorter half life than does Sr^{90}, the older the mixture, the more enriched it becomes in Sr^{90}. Sr^{90} decays to form radioactive yttrium-90, which has a half life of two and a half days. It is known from experiments done in our laboratory that yttrium rather than strontium sticks to tissues which are highly vascularized, such as the kidneys and liver.

It is therefore important to note that the samples were counted after a sufficient time had elapsed so that any yttrium which might have been preferentially taken up by the vascularized visceral organs had time to decay to a negligible amount.

The strontium present in the viscera is, therefore, probably present as a result of the fish swallowing sea water in order to maintain its osmotic equilibrium. A small amount of radioactive sea water trapped in the gut might account for the unexpectedly large amount of strontium which was found in the viscera.

In order to study the rate of uptake of stron-

tium as a function of its concentration, *Tilapia* which had been reared from fertilized eggs in fresh water and acclimatized to sea water in about three weeks were put into carboys containing sea water plus Sr^{90}. The concentration of the Sr^{90} was 1, 10, and 40μc/l.

Since the fish were quite small when they were killed, an aliquot of the entire fish ash was used to determine the amount of radioactivity that was picked up.

Figure 7 shows that at all three concentrations of Sr^{90}, the *rate* of uptake was approximately the same, and that in all instances there was a tendency to level off. These data suggest that a limited number of binding sites for Sr^{90} are available, and that these sites are occupied by way of exchange reactions in a short time. Additional sites would become available only as new tissue was laid down by the growing fish.

It should be noted here that the concentration ratios are much higher for these rapidly growing fish than they are for the mature fish which were described a moment ago. The concentration ratio apparently levels off at about 6 if the fish grows up in sea water containing Sr^{90}. This means that regardless of the amount of Sr^{90} present in the water, these fish will actually concentrate the Sr^{90} approximately six times above its concentration in sea water.

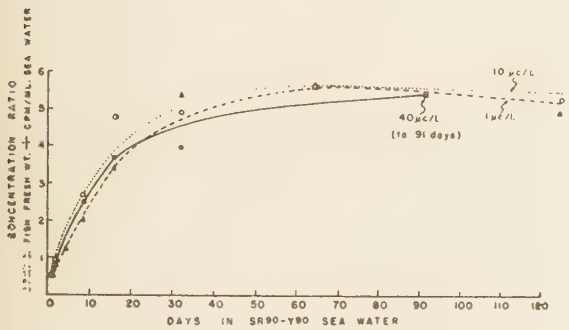


Fig. 7.—The ability of young *Tilapia* raised in sea water containing Sr^{90} - Y^{90} to concentrate Sr.

I must keep coming back to the fact that Sr^{90} is a mixture of Sr^{90} and Y^{90} unless these two elements have been separated by either chemical or biological means. The concentration ratios and the rates of uptake which have been given represent the values obtained for the two isotopes, that is, the samples were not counted until the normal equilibrium was re-established for the pair.

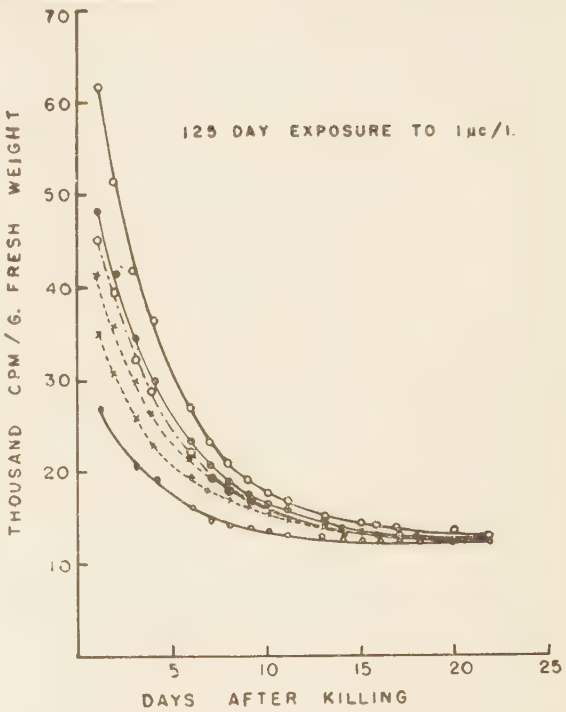


Fig. 8.—The radioactive decay of Sr^{90} - Y^{90} in *Tilapia* ash: 125 days exposure to 1 μc/l.

It is very interesting to see what happens from day to day, however, because these data tell us to what extent the fishes differentiate between Sr and Y. Fig. 8 shows that if the same sample of ash is counted day after day, most of the radioactivity disappears. Since Sr^{90} does not decay perceptibly from day to day, but Y^{90} does, it is clear that these fishes have actually picked up from the water the yttrium in preference to the strontium. Each curve represents a different fish, and you can see that fishes differ considerably in their ability to pick out the yttrium. But after three weeks, when equilibrium has been almost completely re-established, all the fish have about the same amount of radioactivity. One can say that approximately 15,000 counts/minute/g. fresh weight was present in these fishes at equilibrium. If one assumes as a gross approximation that the fish had about 40,000 cpm. at the start, then one can say that only about 37 per cent of the original radioactivity was due to Sr^{90}.

Figure 9 shows that at a concentration level of 10 μc Sr^{90}/l. rather than 1 μc/l., the average "specific activity" is about ten times as high. This is another way of saying what was said earlier, namely, that the concentration ratio is

about the same, regardless of the concentration of the Sr^{90}. Here, however, we see that there is more of a spread in the final amount of Sr^{90} retained, and also that one fish apparently picked up quite a bit of Sr^{90} from the first.

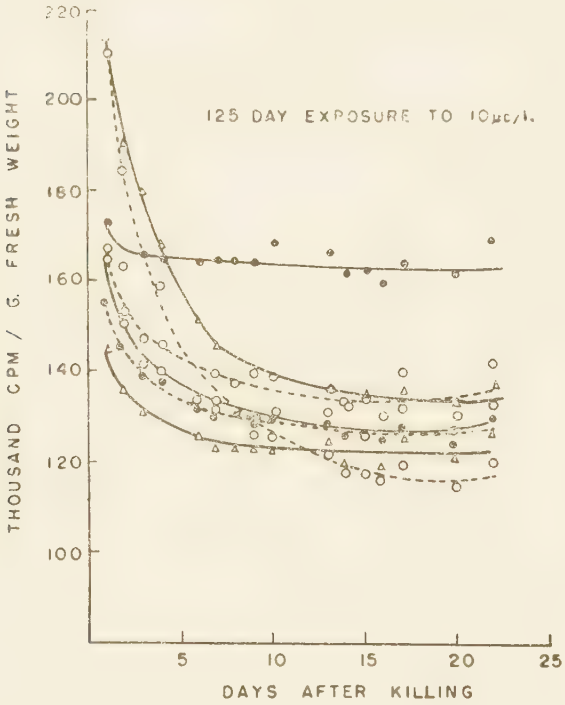


Fig. 9.—The radiocative decay of Sr^{90}-Y^{90} in *Tilapia* ash: 125 days exposure to 10 μc/l.

Figure 10 shows what happened with fish in 40 μc/l. of Sr^{90}. The net result is about the same for all fish, but notice the remarkable difference in the ability to distinguish Sr and Y. The curves at the bottom represent almost an equilibrium mixture, while the curves at the top indicate that these fish concentrated mostly yttrium.

Whether this difference in selectivity is due to the health of the fish as reflected by the amount of slime covering it has, to perhaps the surface-volume ratio, or to some other unknown reasons we cannot state.

The last topic which I would like to talk about has to do with the question: How is strontium carried in fish blood? Is it in the cells or in the plasma? Strontium^{90}-Y^{90} was injected directly into the heart of *Tilapia* fishes, and blood was removed from the renal sinus some time later.

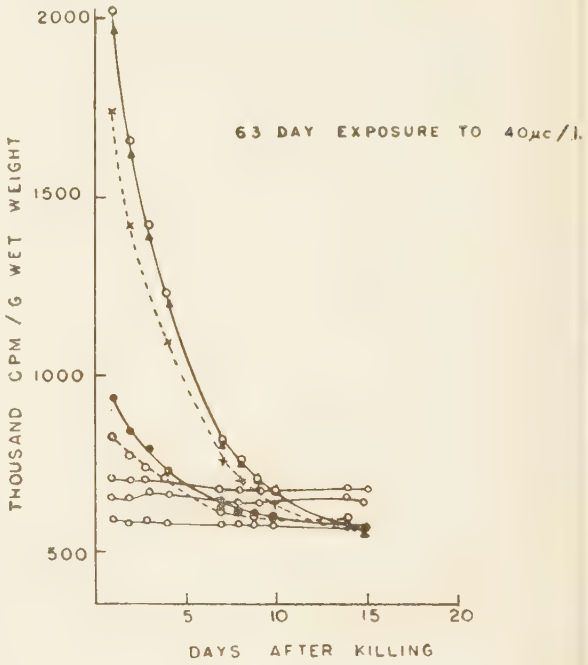


Fig.—10. The radioactive decay of Sr^{90} Y^{90} in *Tilapia* ash: 63 days exposure to 40 μc/l.

These time intervals ranged from five minutes to 8 days. A different fish had to be used for each time interval because the red cell/plasma ratio changes markedly under stress. An aliquot of the whole blood was counted for radioactivity, and then the blood was centrifuged in small bore tubes. The plasma was withdrawn with a capillary syringe and counted. An aliquot of the cells was removed, and the remainder was washed with saline approximately isotonic with fish blood. Both the washed cells and the saline washings were counted. Some cells were also lysed with distilled water, and the ghosts were separated from the cell contents by centrifugation.

Figure 11 shows that the Sr^{90}-Y^{90} very rapidly disappears from the blood. After 24 hours, only one to two per cent of the injected dose remains in the blood. This figure also shows that plasma and whole blood are virtually alike in their content of Sr^{90}. I should point out that the counts/min. are corrected for volume, because

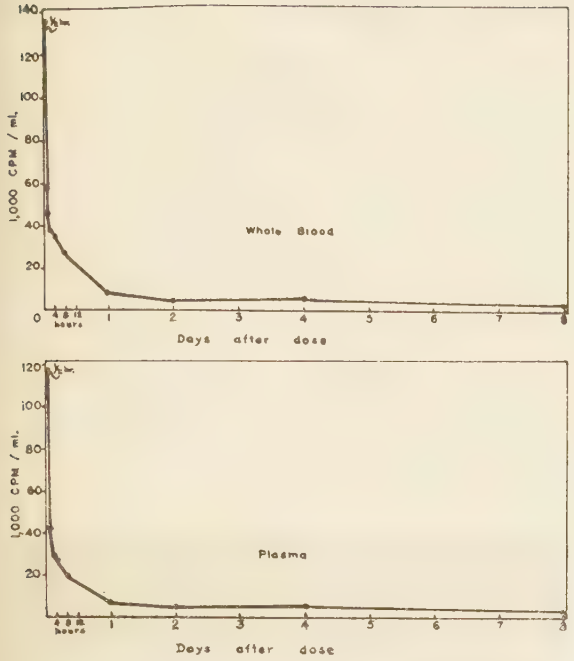


Fig. 11.—The decrease in activity of injected Sr^{90} - Y^{90} in blood.

about 20 per cent of whole blood volume is taken up by the red cells. This means, therefore, that the Sr^{90} is carried almost exclusively in the plasma.

Figure 12 shows what happens to these various samples as they are counted immediately after their preparation and for the following two weeks. The upper curve shows that the saline wash increases in radioactivity. This means that it originally consisted of strontium depleted of its

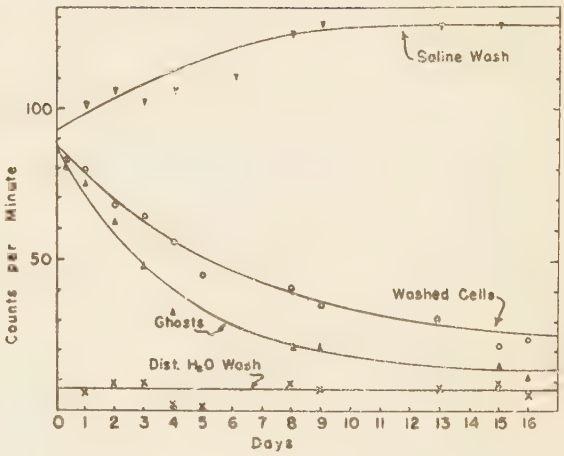


Fig. 12.—Fractionation of Sr^{90} - Y^{90} in fish blood.

yttrium daughter and that the yttrium grew back to its equilibrium value. The next two curves show that both the washed cells and the stroma or ghosts of these cells declined in radioactivity. This is due to the disappearance of the short lived yttrium which they had picked up. The bottom curve which is a straight line indicates that the small amount of radoactivity which was either removed from the cell surface or was present in the interior was a mixture of Sr-Y.

In summary, our results have shown that strontium is rapidly absorbed from the gut and transported by the plasma throughout the entire fish body. Within a day, only a few per cent of the dose remains within the body. Of the strontium remaining, the bulk of it is associated with the bones, integument and gills, which of course contain both bone and cartilage.

A PRELIMINARY RADIOACTIVITY SURVEY ALONG THE CALIFORNIA COAST THROUGH DISPOSAL AREAS†

J.L. FAUGHN, T.R. FOLSOM, J.D. ISAACS, F.D. JENNINGS, DEC. MARTIN, JR., L.E. MILLER, and R.L. WISNER

Division of Marine Resources, Scripps Institution of Oceanography, University of California, La Jolla, California, U.S.A.

What is perhaps one of the oldest oceanic activity dumps in existence is located off the central California Coast and has been accumulating active waste for well over ten years. More recently another disposal area has been established off the Southern California Coast.

The northern dumping area, about 40 miles outside of San Francisco Bay, has received since 1946 about 10,000 packages of active material estimated to amount to about 10,000 curies. The southern dump nearer to Los Angeles Harbor has received at least 825 disposal drums containing roughly 40 curies of active waste material—mostly of the sort discarded by smaller research laboratories.

Since 1950, the responsibility for disposal has been vested in the Technical Services Branch of the War Department, which has established the requirement for weighing all packages to prevent immediate return of dangerous waste to the surface. The Atomic Energy Commission and the University of California Radiation Laboratory have cooperated in devising the present technique for disposal and packaging. More recently the Scripps Institution of Oceanography has been invited to assist in this program, and some of its first findings will be described briefly here.

The staff at Scripps were asked to make actual tests of disposal packages at sea, and to make a preliminary inspection of the waters and sediment near the disposal areas.

Present Disposal Packages

All of the dumping in the southern area has been by means of 55 gallon steel drums weighted and capped with concrete. The northern dump has received other packages; for example, a cast concrete cube 4 feet on edge and weighing 3,500 pounds has been used also.

Figure 1 is a photograph of a standard oil drum filled with concrete (but with no activity) in a manner customarily used for disposal. This drum was being tested at the request of the Radiation Laboratory, and is here seen at the side of the vessel suspended on a steel cable just after being hauled up from a depth of 1,200 meters. It will be seen that the sides are distorted due to external pressure. Several of these drums and also one of the large concrete cubrial containers were tested by sudden lowering at sea.

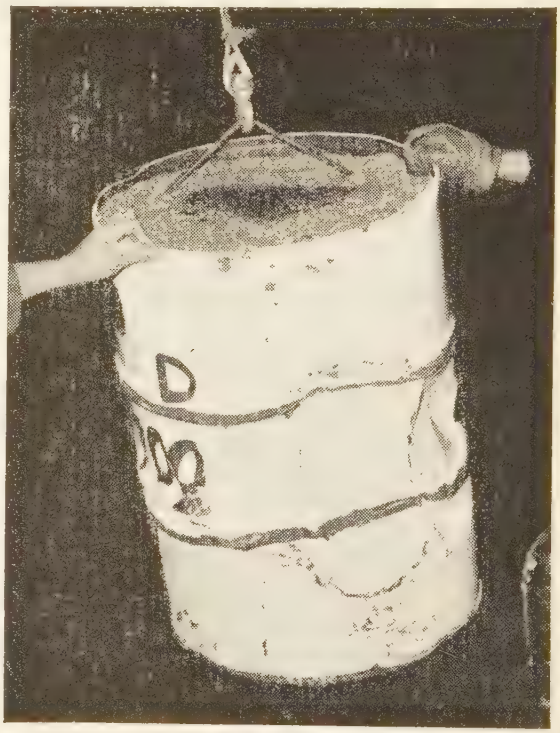


Fig. 1.—Standard oil drum used for disposal of active waste material.

† This cruise was sponsored jointly by the San Francisco Operations Office of the United States Atomic Energy Commission and the Radiation Safety Division of the University of California Laboratory at Livermore, under guidance of Mr. Nels Garden.

Contribution of Scripps Institution of Oceanography, New Series, No. 000.

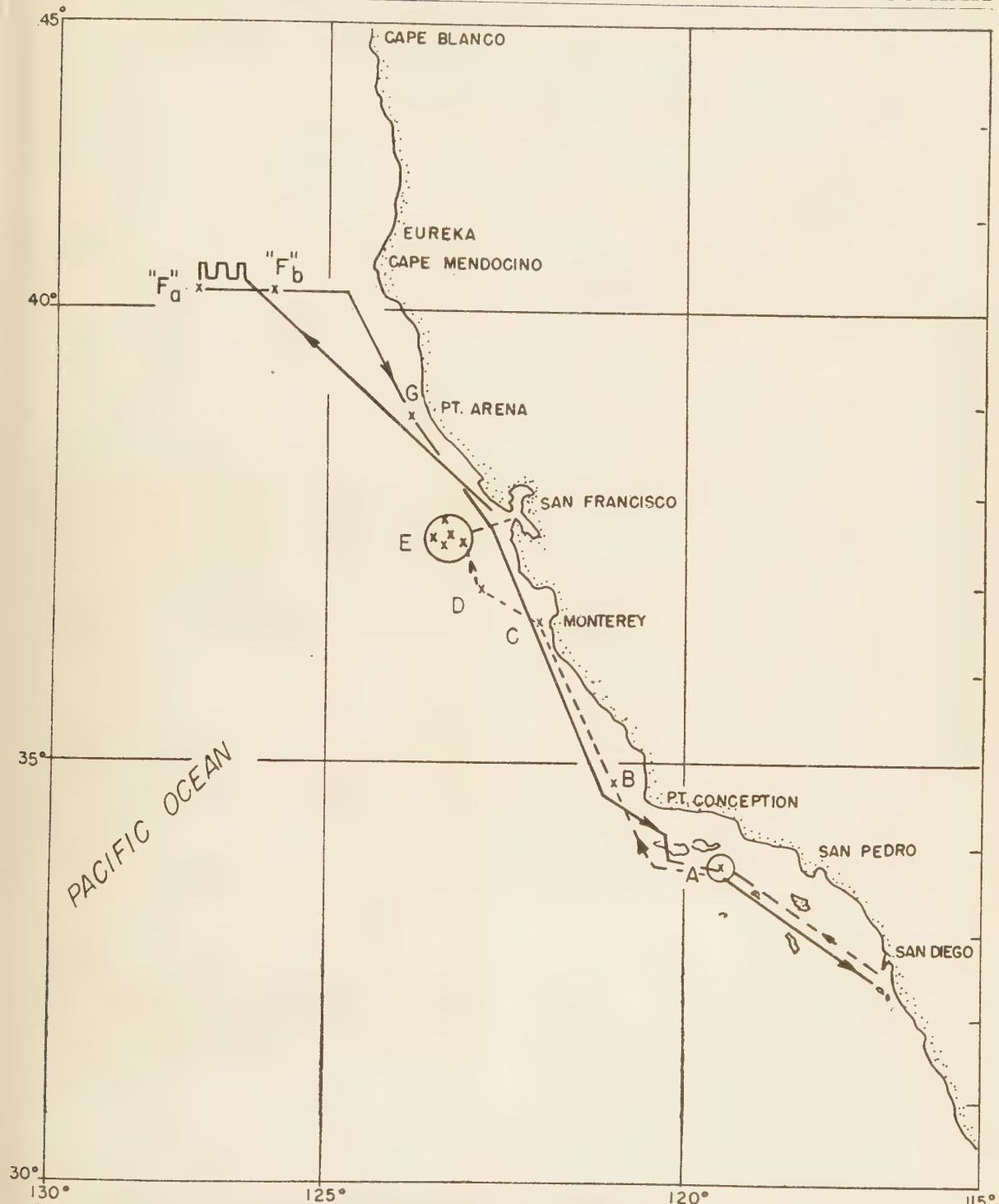


Fig. 2.— University of California joint Scripps Institution of Oceanography and University of California Radiation Laboratory coastal survey including disposal areas, April, 1957.

The actual disintegration rate on the sea floor of packages such as these is not known; it has been the subject of much discussion and conjecture. It is likely that sooner or later the confined activity gets out into the sea. Therefore an attempt has recently been made to see whether this could readily be detected.

The Radiological Survey

In April, 1957, one of the oceanographic ships of the Scripps Institution, the 750 ton diesel-electric tug *Spencer F. Baird*, was sent from San Diego Harbor northward as far as the Mendocino Escarpment off Northern California. Both of the California disposal areas were traversed. Fig. 2 shows the cruise route. Table 1 lists station positions and briefly the character of the oceanographic work done and the samples taken. The scientific staff consisted of twelve men besides the ship's crew. Much of the work arose from the need for taking water samples much larger than is customary and from requirements for keeping them uncontaminated. Attempts were made toward taking sediment samples more suitable for radioanalyses than are commonly brought home for geological study.

Handling Large Water Samples

Radioanalysis at trace levels frequently requires large samples. Two procedures were used on the cruise for concentrating radioactivity specimens at sea, and a few large unconcentrated samples also were taken as controls. One method utilized the immediate carbonate precipitation from 70 to 120 liter samples by use of ammonia gas and ferric salts. A large vacuum filter suitable for shipboard use was constructed from Lucite, just before sailing time. The wet precipitates were brought home in small polyethylene kitchen canisters.

Vacuum Evaporator

The second method of concentration made use of the special vacuum evaporator that had been built for this sort of work at Scripps Institution—Figs. 3 and 4. This apparatus, which will be described in more detail elsewhere, consists of a complete water concentrating system having its own 8 kw. steam boiler which can be taken to sea as a unit and operated without hazard by use of the ship's electric system. Dilute solutions can be evaporated at rates up to about five gallons per hour, and at lower rates. Evaporation can be carried out at any temperature between about 120° C. and sea temperature. For convenient routine concentration on this trip, 23 liter samples of sea water were concentrated to 1 liter, and three of such samples usually combined in one polyethylene storage canister. (At this level of physical concentration, sea water can be poured as a milky fluid which later crystalizes further into a solid.)

It was found necessary to store these unpreserved samples under refrigeration, because they are attacked slowly by halophytic bacteria.

Problem of Sampling Bottom for Traces of Activity

It can be assumed that any recent bottom contamination lies mostly within a thin layer near the top of the sediments. Unfortunately, at present there is no entirely satisfactory device available for scraping large samples from the upper few centimeters, at least none able to bring it to the surface without contamination. The usual coring and dredging devices either cut too deeply, or else contaminate their loads while passing through the upper water layers; some have both failings. Several standard devices and also two hastily improvised novel ones were tried with moderate satisfaction. Only one sample clearly contained the undisturbed top layer of the mud; however, several large samples of sediments suitable for estimating the closely underlying natural activities were taken.

Biological Specimens

Numerous standard zooplankton hauls were made as well as two very ample catches that were made with the Isaacs-Kidd midwater trawl at 1,000 meters depth and within the dumping areas. Bathypelagic organisms were found in mud-dredge hauls at 1,016 meters and 1,630 meters and preserved as radiospecimens.

Analyses

So far, only cursory inspection of the samples has been possible, but some equipment suitable for a more detailed study is now being set up. The specimens have been preserved by the best known means. At the present it can be stated merely that:

1. In the surface ocean water and especially in floating organisms such as *Velella* and certain barnacles, the gamma activity has roughly the magnitude and character of gamma ray activity now frequently seen in setal sea weeds. Fission products predominate. One *Velella* specimen had a gamma peak at 0.745 mev with activity here of about 2,000 counts/min/kg.

Table 1.

Results of April, 1957 Cruise
through California Disposal Areas.

STATION A — April 12-13, 1957
Lat. 33°39′N.
Long. 119°29′W.
Depth—1,035 fathoms

Work done:
Evaporator — 69 liters from surface
69 liters from 1000 meters
Precipitation — 128 liters from surface
Cores — 3 Phleger cores
1 Lamont core
Mud samples— 2 bucket samples
Rock dredge
Diving dredge
Midwater trawl
Plankton tow

STATION B — April 14, 1957
Lat. 33°55′N.
Long. 121°57′W.
Depth—1,370 fathoms

Work done:
Evaporator — 69 liters (surface)
69 liters (1,000 meters)
Precipitation — 120 liters (surface)
Cores — 1 Phleger core
Plankton tow

STATION C — April 14, 1957
Lat. 36°42 N.
Long. 122°09′W.
Depth—700 fathoms

Work done:
Evaporator — 69 liters (surface)
69 liters (1,000 meters)
Precipitation — 120 liters (surface)
Cores — 1 Phleger core
1 Bucket mud sample
Plankton tow

STATION D — April 15,1957
Lat. 37°00′N.
Long. 122°57′W.
Depth—1,050 fathoms

Work done:
Precipitation — 70 liters (surface)
1 Phleger core
1 mud sample
1 Plankton tow

STATION E — April 15, 1957
Lat. 37°38′N.
Long. 123°18′W.
Depth—1,650 to 25 fathoms

Work done:
Evaporator — 69 liters (surface)
69 liters (1,000 meters)
Precipitation — 170 liters (surface)
Cores — 7 Phleger cores at various depths
Mud samples— 6 at various depths
Midwater trawl
2 Plankton tows

STATION F - G — April 19, 1957
Lat. 40°14′N.
Long. 128°00′W.
Depth—Variable

Work done:
Evaporator — 69 liters (surface)
69 liters (1,000 meters)
Precipitation — 120 liters (surface)
70 liters (surface)
Plankton tow

STATION A′ — April 22, 1957
Lat. 33°46′N.
Long. 119°37′W.
Depth—1,000 fathoms

Work done:
Precipitation — 120 liters (surface)
Phleger core

2. Zooplankton which were sampled to 200 meters depth showed activity such as can come from fallout; and, from the gamma spectra, it appears they concentrate certain isotopes preferentially. For example, gamma activity peaks at 0.745 mev are not uncommon with intensities of 100 c/m/kg. There is no certainty that all this artificial activity comes by way of the sky, however.

3. Zooplankton taken from 1,000 meters depth show only a barely significant trace of activity at energies which might indicate the presence of the ruthenium fission products. This might be due to the vertical migrations of these organisms.

4. The bottom sediment samples indicated strong natural gamma activity corresponding to the radium and thorium daughters. For example, one sediment specimen apparently coming from the upper 10 cm. had a radium concentration 2×10^{-12} grams Ra/gram dry weight. Because of the abundance of radium and thorium it is difficult to detect small amounts of artificial activity. The only hope for the present specimens lies in extremely careful radio assay after the most complete possible chemical separation natural activities.

Conclusions

1. A preliminary survey by standard oceanographic methods has not disclosed easily detectable amounts of artificial contaminating activity even in the immediate vicinity of the oldest official marine disposal area.

2. It is evident from this brief experience that special techniques, both radiological and oceanographic, must be further perfected for efficient low level radioactive monitoring of oceanic areas.

LEGEND TO FIG. 3.

SCRIPPS INSTITUTION OF OCEANOGRAPHY SEA WATER CONCENTRATOR

HEATING SYSTEM

A. Switch Box 12 kw.
B. Heater Element 3 kw.
C. Boiler
D. Heat Lagging
E. Water Glass
F. Steam Flue
G. Removeable Stainless Evaporator Tube
H. Boiler Condensate Return
I. Thermometer Well
J. Steam Gage, Pressure and Vacuum
K. Safety Valve
L. Vacuum Vent from Boiler

CONCENTRATING SYSTEM

a. Supply Bottle Seawater
b. Inlet Valve
c. Stuffing Joint Between Evaporator Tube and Concentrate Return
d. Stuffing Seal of Steam Jacket
e. Detachable Elbow
f. Vapor Expansion Chamber
g. Spume Deflector
h. Pyrex Concentrate Reservoir
i. Concentrate Return
j. Concentrate Dump
k. Concentrate Receiver
l. Plug for Gages and Thermometers

VACUUM SYSTEM

1. Plastic Insulating Block
2. Post Support
3. Vapor Condenser Tube
4. Water Jacket
5. Helical Water Director
6. Vapor Condensate Drain
7. Condensate Receiver
8. Centrifugal Pump
9. Sea Water Input
10. Condenser Output, Ejector Input
11. Water Driven Ejector
12. Air Exhaust
13. Cooling and Pumping Water Outflow
14. Water Pressure Gage
15. Vacuum Gage

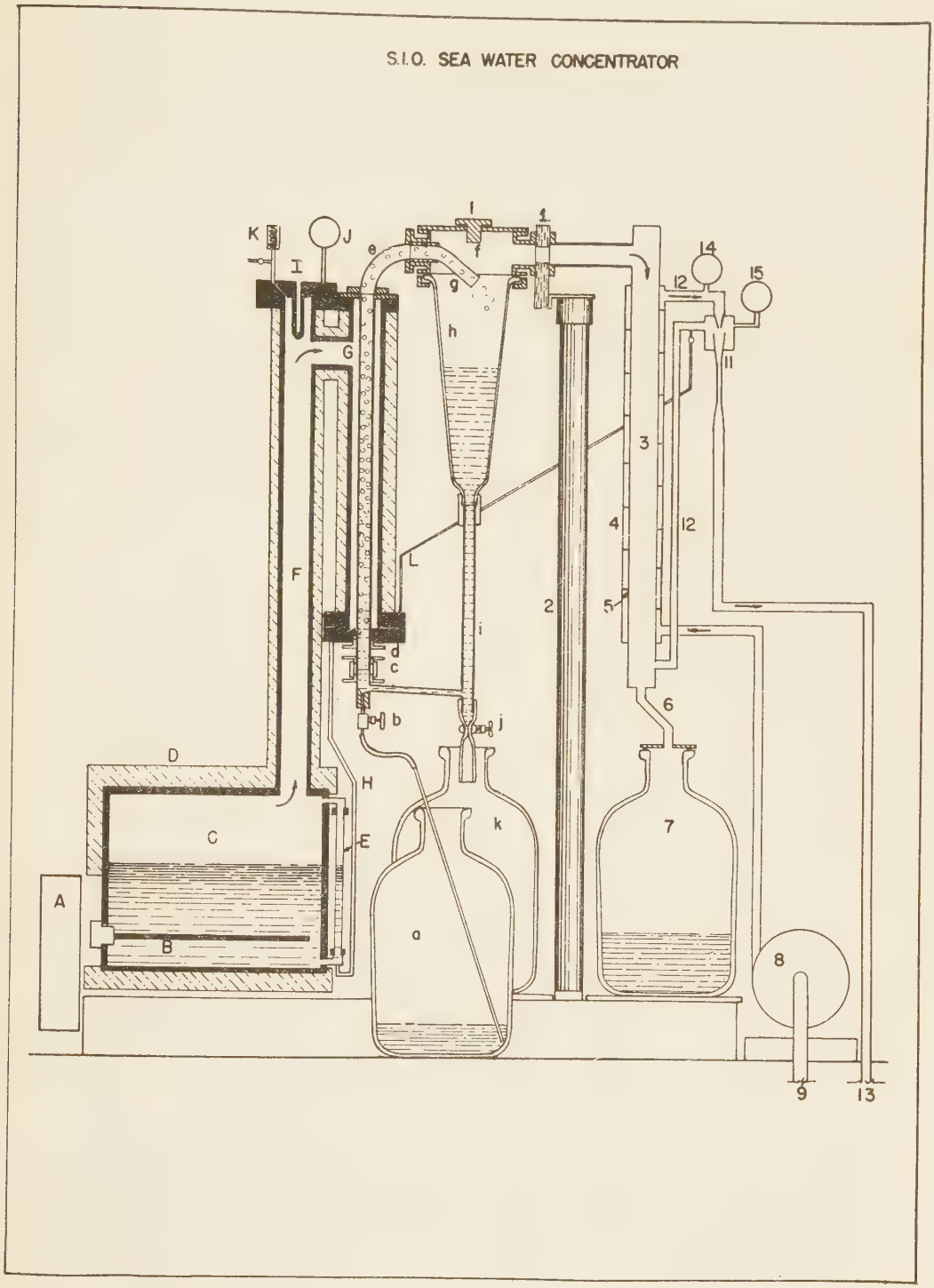


Fig. 3.—Diagram of sea water concentrator built by Scripps Institution of Oceanography.

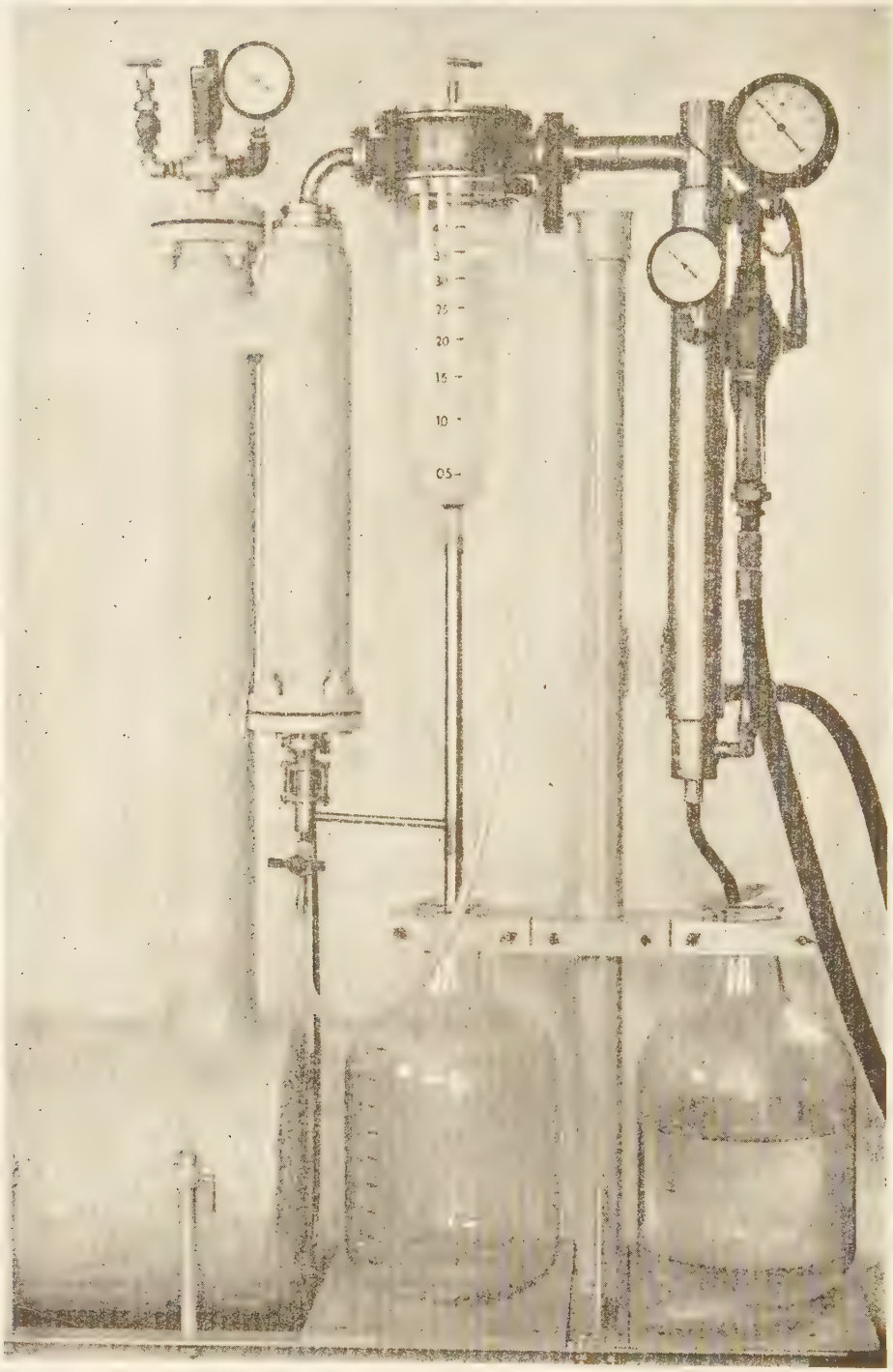


Fig. 4.—Sea water concentrator built by Scripps Institution of Oceanography.

DIRECT UPTAKE OF RADIOISOTOPES BY FISH

TETUO TOMIYAMA and KUNIO KOBAYASHI

Faculty of Agriculture, Kyushu University, Fukuoka, Japan.

INTRODUCTION

It has been thought that fish become contaminated with fission products or radioisotopes through their foods *(1)*. This postulation for the contamination pathway was based on the fact that lower food rank organisms were more heavily contaminated than higher food rank organisms, and further, the alimentary tract of the fish was in general more contaminated than any other organ.

However, the authors of this paper have reported several evidences that fish can be contaminated directly by radioisotopes dissolved in water; in the case of the fresh water fish the contamination is mostly through the gills, and in marine fish it is through both the gills and alimentary tract *(3, 4, 5, 6, 7)*.

This paper deals with further studies on the pathway of uptake of Sr^{90} (Y^{90}), Y^{91}, Zr^{95} (Nb^{95}), and I^{131} by eel, carp, and goldfish.

EXPERIMENTAL METHOD

The method used was principally the same as that described in a previous paper *(6)*. Eels were employed in order to scrutinize the pathway of uptake under both fresh water and sea water conditions. The importance of the gills as the pathway was shown by separating the head part from the remainder with two thin rubber membranes. The role of the alimentary tract for the uptake was tested by stopping the stomach part with calcium alginate. The radioactivity of various test tissues was measured by the G-M counter on the ashed sample except for measuring I^{131}. In this case, the sample tissue was carbonized after the addition of potassium hydroxide before it was subjected to the radioactivity measurement. The estimation of Sr^{90} and Y^{90} was carried out simply by calculation, as the betaradiation of Sr^{90} was completely absorbed and that of Y^{90} was reduced to 53 per cent by using an aluminum absorber of 129mg. per cm^2.

Table 1.
Absorption of Sr^{90} (Y^{90}) by eel.*

Water	Fresh water		Sea water	
Tissue \ Time of exp. (hrs.)	5	25	5	25
Blood	64	259	11	29
Gills	1,469	1,577	148	862
Fin	225	696	46	116
Vertebra	64	629	10	61
Scale	837	2,570	121	413
Surface mucus	78	260	54	76
Skin	47	149	14	19
Muscle	13	35	4	9
Liver	26	123	10	14
Gall bladder	27	110	28	36
Spleen	52	130	36	89
Kidney	43	135	12	29
Air bladder	46	194	19	20
Heart	78	226	37	87
Body weight (g.)	203	214	154	262
	187	175	140	247

* Values are expressed as cpm. per g. of fresh tissues. Water used: radioactivity, 4,900 cpm/cc; temp., 14-16° C.

RESULTS AND DISCUSSIONS

Table 1 shows the uptake of Sr^{90} (Y^{90}) by eel under fresh water and sea water conditions. It should be noted that the uptake in sea water by various tissues was in general smaller except by the alimentary tract. A smaller uptake in sea water can be accounted for by the fact that sea water contains much larger amounts of calcium besides strontium than does fresh water. A greater amount of Sr^{90} (Y^{90}) in the alimentary tract under sea water conditions, as presented in Table 2, is apparently due to drinking sea water to obtain water required for the metabolism as was postulated by Smith *(2)*.

Table 3 and 4 show the effect of the obstruction of the stomach on the uptake of the radioisotope under the fresh water and sea water conditions, respectively. Contrary to expectation, the data given in these table indicate that under the sea water condition the increase in Sr^{90} (Y^{90}) in various tissues and organs occurred more significantly in the eel with obstructed stomach than without it. This abnormal increase in uptake of Sr^{90} (Y^{90}) from sea water by the eel with the obstructed stomach seems to be due to the increase in the surface absorption of water probably through the gills in order to compensate the normal oral supply of the water required for metabolism in sea water. Under normal conditions it is clear from Table 2 that the eel in the sea water drank a far greater amount of water than the eel in fresh water.

The approximate estimate of Sr^{90} and Y^{90} in various tissues and organs shows that Y^{90} far exceeded Sr^{90} in the gills, surface mucus and liver both in the fresh water and sea water condition (Table 5). The enrichment of yttrium in the gills and surface mucus was clearly demonstrated when the eel was exposed to Y^{91} (Table 6). However, when Sr^{90} (Y^{90}) was administered intramuscularly, the ratio of Sr^{90} to Y^{90} was nearly unity in the gills whereas it was greater in the surface mucus and smaller in the liver (Table 7). The selective concentration of yttrium in the liver was also manifested after intramuscular administration of Y^{91} (Table 8). It is to be noticed that the hard tissues generally contain more Sr^{90} than Y^{90}.

Table 2.

Radioactivity of Sr^{90} (Y^{90}) in contents of stomach and intestine of eel.*

Water	Temp. (°C)	Time of exp. (hr.)	Acty. of s. c. (cpm.)	Acty. of i. c. (cpm.)	Total acty. in contents of s. and i. (cpm.)	Body weight (g.)
Fresh Water	14	5	39	78	117	198
	16	25	467	667	1,134	204
			2,944	3,560	6,504	173
	22	5	4	56	60	114
			310	647	957	178
	24	25	27	127	154	143
			421	1,585	2,006	135
Sea Water	14	5	424	377	801	147
	16	25	404	49,923	50,327	183
			1,200	94,270	95,470	255
	22	5	56	3,227	3,283	93
			1,724	12,687	14,410	147
	24	25	44	30,578	30,622	115
			1,836	9,425	11,261	146

All the values are corrected for difference in radioactivity of the water used, viz., based on radioactivity at level of 10,000 cpm/cc.

About 94% of Sr^{90} (Y^{90}) in the eel blood was in the plasma both in the fesh water and sea water condition. It is of interest that the extrarenal excretion of Sr^{90} (Y^{90}) occurred very little in the fresh water condition while it was as much as 70% in the sea water condition.

Table 3.
Absorption of Sr^{90} (Y^{90}) in fresh water by eel with obstructed oesophagus.*

Treatment of oesophagus	No obstruction		With obstruction	
Tissue \ Time of exposure (hrs.)	5	25	5	25
Blood	124	602	292	447
Gills	1,417	4,962	4,406	8,398
Fin	411	3,815	814	2,778
Vertebra	154	2,758	350	1,944
Scale	1,047	12,180	2,386	10,324
Surface mucus	694	2,668	1,148	3,444
Skin	66	409	113	319
Muscle	20	94	30	77
Liver	48	461	169	706
Gall bladder	41	425	63	345
Spleen	57	221	177	1,410
Kidney	40	292	231	956
Air bladder	77	514	208	402
Heart	91	394	283	538
Body weight (g.)	191	143	172	158
	164	126	161	134

* Values are expressed as cpm. per g. of fresh tissues. Water used: fresh water; radioactivity, 11,000 cpm/cc; temp., 22-24° C.

Table 4.
Absorption of Sr^{90} (Y^{90}) in sea water by eel with obstructed oesophagus.*

Treatment of oesophagus	No obstruction		With obstruction	
Tissue \ Time of exposure (hrs.)	5	25	5	25
Blood	52	121	274	819
Gills	1,145	4,060	2,437	3,554
Fin	100	543	822	2,579
Vertebra	53	379	419	3,007
Scale	356	1,757	2,896	10,260
Surface mucus	378	1,267	512	716
Skin	22	63	132	605
Muscle	10	27	47	251
Liver	19	160	464	2,268
Gall bladder	14	37	84	578
Spleen	31	43	297	2,646
Kidney	24	78	216	2,929
Air bladder	24	89	193	719
Heart	43	100	340	682
Body weight (g.)	159	154	150	156
	135	137	134	139

* Values are expressed as cpm. per g. of fresh tissues. Water used: sea water; radioactivity, 11,000 cpm/cc; temp., 22-24 ° C

A study similar to that on the pathway of uptake of Sr^{90} (Y^{90}) was made of Zr^{95} (Nb^{95}). When an eel was exposed to Zr^{95} (Nb^{95}), an exceedingly high level was found in the gills and surface mucus, and a very small trace in the other tissues and organs (Table 9). The uptake from sea water was smaller than that from fresh water. However, when the isotope was administered intramuscularly, the internal organs showed more activity than the hard tissues and gills, and the surface mucus showed only a trace activity (Table 10). About 92% of the activity in the blood existed in the plasma. The excretion was very slow and about 64% of the total excreted activity was eliminated through renal route both in the fresh water and sea water condition.

Table 5.
Ratio of Sr^{90} to Y^{90} in various tissues of eel.

Water	Fresh water		Sea water	
Tissue \ Time of exposure (hrs.)	5	25	5	25
Blood	1.50	1.63	2.23	1.13
Gills	0.22	0.16	0.27	0.15
Fin	1.13	2.70	2.23	1.78
Vertebra	1.70	1.86	1.17	2.57
Scale	2.57	2.45	1.22	2.70
Surface mucus	0.41	0.75	0.52	0.75
Skin	0.79	3.17	1.13	1.63
Muscle	1.56	2.45	2.23	2.03
Liver	0.72	0.61	0.59	0.64
Gall bladder	1.63	3.55	2.23	1.56
Spleen	0.61	1.27	0.75	0.64
Kidney	1.13	1.33	1.08	1.04
Air bladder	1.04	3.17	1.22	2.23
Heart	0.82	0.89	1.04	0.92

Table 6.
Absorption of Y^{91} by eel.*

Water	Fresh water		Sea water	
Tissue \ Time of exposure (hrs.)	5	25	5	25
Blood	32	65	9	22
Gills	6,890	17,914	980	1,517
Fin	300	584	102	214
Vertebra	19	65	12	22
Scale	342	584	36	119
Surface mucus	644	967	59	140
Skin	33	71	0	13
Muscle	10	30	0	4
Liver	59	138	13	74
Gall bladder	11	92	0	33
Spleen	47	110	0	10
Kidney	71	76	13	114
Air bladder	32	40	6	32
Heart	30	168	19	88
Body weight (g.)	384	278	310	452

* Values are expressed as cpm. per g. of fresh tissues. Water used: radioactivity, 4,900 cpm/cc; temp., 14-16 °C.

When goldfish was kept in water containing I^{131}, the rate of uptake varied with the amount of the carrier. In case of carrier-free state a sharp peak in the uptake was noticed at a 5-hour exposure. No peak was observed within one day when the carrier was added. A similar phenomenon was observed when the fish was exposed to I^{131} for 10 days, i.e., a peak of the uptake being manifested at one-day exposure in case of the carrier-free I^{131} as contrasted to the carrier containing I^{131}. These peculiar phenomena observed may be partly due to a high rate of elimination

Table 7.
Distribution in eel of Sr^{90} (Y^{90}) following intramuscular administration.*

Tissue	Fresh water			Sea water		
	Radio-acty. (cpm/g)	Ratio to blood	$\frac{Sr^{90}}{Y^{90}}$	Radio-acty. (cpm/g)	Ratio to blood	$\frac{Sr^{90}}{Y^{90}}$
Blood	5,613	1.00	2.13	5,994	1.00	2.45
Gills	12,082	2.15	1.38	9,505	1.59	1.33
Fin	16,866	3.01	1.27	17,933	2.99	1.13
Vertebra	25,119	4.48	1.56	19,977	3.33	1.56
Scale	114,704	20.44	1.38	55,792	9.31	1.17
Surface mucus	1,004	0.18	2.03	506	0.08	2.33
Skin	2,725	0.49	2.13	3,828	0.64	1.94
Muscle	811	0.14	2.13	909	0.15	2.03
Liver	6,913	1.23	0.25	3,855	0.64	0.49
Gall bladder	2,330	0.42	1.78	2,790	0.47	2.13
Spleen	2,787	0.50	1.38	3,535	0.59	0.85
Kidney	3,590	0.64	0.85	3,949	0.66	1.13
Air bladder	3,738	0.67	2.23	4,175	0.70	2.23
Heart	4,734	0.84	1.13	4,434	0.74	1.44
Body weight (g.)		238			240	

* Sr^{90} (Y^{90}) administered, about 1.25×10^6 cpm. per 238 g. and 240 g. respectively; time of exposure, 24 hrs.; temp., 14-16 °C.

Table 8.
Distribution in eel of Y^{91} following intramuscular administration.*

Tissue	Fresh water		Sea water	
	Radioactivity (cpm/g)	Ratio to blood	Radioactivity (cpm/g)	Ratio to blood
Blood	6,067	1.00	6,257	1.00
Gills	2,986	0.49	5,938	0.95
Fin	6,165	1.02	8,257	1.32
Vertebra	1,780	0.29	3,415	0.55
Scale	20,216	3.33	23,979	3.83
Surface mucus	98	0.02	135	0.02
Skin	603	0.10	768	0.12
Muscle	148	0.02	430	0.07
Liver	6,135	1.01	28,954	4.63
Gall bladder	339	0.06	788	0.13
Spleen	6,340	1.05	9,339	1.49
Kidney	14,743	2.43	22,790	3.64
Air bladder	1,256	0.21	1,140	0.18
Heart	3,132	0.52	6,272	1.00
Body weight (g.)	232		173	

* Y^{91} administered, about 1.25×10^6 cpm. per 232g. and 173g. respectively; time of exposure, 24 hrs.; temp., 14-16 °C.

Table 9.
Absorption of Zr^{95} (Nb^{95}) by eel.*

Water	Fresh water		Sea water	
Tissue \ Time of exposure (hrs.)	5	25	5	25
Blood	4	12	5	11
Gills	219	4,469	113	1,475
Fin	15	157	11	49
Vertebra	0	3	0	17
Scale	3	30	5	44
Surface mucus	51	776	24	150
Skin	5	5	4	23
Muscle	0	1	0	1
Liver	0	5	1	5
Gall bladder	0	5	0	3
Spleen	8	33	5	35
Kidney	2	12	2	17
Air bladder	0	8	0	8
Heart	11	49	5	35
Body weight (g.)	153 126	185 175	133 126	171 131

* Values are expressed as cpm. per g. of fresh tissues. Water used: radioactivity, 1,450 cpm/cc; temp., 14-16 °C

Table 10.
Distribution in eel of Zr^{95} (Nb^{95}) following intramuscular administration.*

Tissue	Fresh water		Sea water	
	Radioactivity (cpm/g)	Ratio to blood	Radioactivity (cpm/g)	Ratio to blood
Blood	52,006	1.00	37,425	1.00
Gills	9,312	0.18	10,823	0.29
Fin	17,019	0.33	11,177	0.30
Vertebra	5,165	0.10	7,245	0.20
Scale	15,711	0.30	12,279	0.33
Surface mucus	898	0.02	669	0.02
Skin	14,505	0.28	12,439	0.33
Muscle	925	0.02	988	0.03
Liver	10,707	0.21	12,421	0.33
Gall bladder	6,179	0.12	6,302	0.17
Spleen	25,139	0.48	52,159	1.39
Kidney	49,310	0.95	74,231	1.98
Air bladder	10,662	0.21	15,051	0.40
Heart	23,843	0.46	25,067	0.67
Body weight (g.)	230		213	

*Zr^{95} (Nb^{95}) administered, about 1.8×10^6 cpm. per 230 g. and 213 g. respectively; time of exposure, 25 hrs.; temp., 15-17 °C.

of iodine which is evidenced by the highest level of iodine being found in the kidney so far as various organs were examined. In case of the carrier-containing I^{131} the amount of iodine circulating in the fish might far exceed the capacity of elimination through the kidney. When I^{131} was absorbed by carp, its distribution in various tissues was of comparable level except for kidney and blood. A little more uptake was produced by exposing the head part and also by closing the alimentary tract (Tables 11 and 12). These data suggest that I^{131} in fresh water can be directly uptaken not only through the gills but also all over the surface of the fish.

When I^{131} was administered intramuscularly, the highest level was found in the kidney and the blood (Table 13). About 82% of I^{131} in the blood was in the plasma. About 67% of I^{131} excreted was eliminated through the renal route.

It will be of interest to know how much radioisotopes can be concentrated by various tissues and organs from the blood after the intramuscular administration of the various radioisotopes. The data in Table 14 indicate that Sr^{90} (Y^{90}) and Y^{91} are highly concentrated in the scales while Zr^{95} (Nb^{95}), I^{131} and Y^{91} are concentrated in the kidney. No significant difference in the distribution patterns exists between the fresh water and sea water condition.

Table 11.
Absorption of I^{131} by carp from head part and remainder part*

Site of absorpt. / Tissue	Total body	Head part	Remainder part
Blood	114	50	24
Gills	67	32	12
Fin	69	41	20
Vertebra	48	20	14
Scale	41	31	18
Skin	46	30	23
Muscle	12	10	5
Liver	56	30	13
Gall bladder	50	89	10
Spleen	55	25	12
Kidney	117	748	78
Air bladder	95	44	15
Heart	69	42	15
Gonad	♀ 42	♂ 29	♂ 15
Body weight(g.)	460	400	390

* Values are expressed as cpm. per g. of fresh tissues. Water used: radioactivity, 1,000 cpm/cc.; I, 1 mg/l.; urethane, 0.25%; time of exposure, 24 hrs.; temp., 20-22°C.

Table 12.
Absorption of I^{131} by carp with obstructed oesophagus.*

Treatment of oeso. / Tissue	No obstruction	With obstruction
Blood	114	161
Gills	67	74
Fin	69	95
Vertebra	48	66
Scale	41	53
Skin	46	62
Muscle	12	15
Liver	56	87
Gall bladder	50	143
Spleen	55	88
Kidney	117	132
Air bladder	95	128
Heart	69	80
Gonad	42 ♀	58 ♀
Body weight (g.)	460	590

* Values are expressed as cpm. per g. of fresh tissues. Water used: radioactivity, 1,000 cpm/cc.; urethane, 0.25%; I, 1 mg/l.; temp., 20-22°C.; time of exposure, 24 hrs.

Table 13.
Distribution in carp of I^{131} following intramuscular administration.*

Tissue	Radioactivity (cpm/g.)	Ratio to blood
Blood	653	1.00
Gills	252	0.39
Fin	381	0.58
Vertebra	243	0.37
Scale	163	0.25
Skin	290	0.44
Muscle	147	0.23
Liver	444	0.68
Gall bladder	239	0.37
Spleen	317	0.49
Kidney	1,419	2.17
Air bladder	403	0.62
Heart	319	0.49
Gonad ♂	248	0.38
Body weight (g.)	450	

* I^{131} administered, about 2×10^5 cpm. per 450 g.; time of exposure, 24 hrs. Water used: urethane, 0.25%; temp., 20-22°C.

Table 14.

Radioactivity ratio of various tissues to blood after the intramuscular administration of various radioisotopes.*

Tissue	Sr^{90} (Y^{90})		Y^{91}		Zr^{95} (Nb^{95})		I^{131}
	Eel		Eel		Eel		Carp
	F.w.	S.w.	F.w.	S.w.	F.w.	S.w.	F.w.
Blood	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Gills	2.15	1.59	0.49	0.95	0.18	0.29	0.39
Fin	3.01	2.99	1.02	1.32	0.33	0.30	0.54
Vertebra	4.48	3.33	0.29	0.55	0.10	0.20	0.37
Scale	20.44	9.31	3.33	3.83	0.30	0.33	0.25
Skin	0.49	0.64	0.10	0.12	0.28	0.33	0.44
Muscle	0.14	0.15	0.02	0.07	0.02	0.03	0.23
Liver	1.23	0.64	1.01	4.63	0.21	0.33	0.68
Gall bladder	0.42	0.47	0.06	0.13	0.12	0.17	0.37
Spleen	0.50	0.59	1.05	1.49	0.48	1.39	0.49
Kidney	0.64	0.66	2.43	3.64	0.95	1.98	2.17
Air bladder	0.67	0.70	0.21	0.18	0.21	0.40	0.62
Heart	0.84	0.74	0.52	1.00	0.46	0.67	0.49

*Time of exposure, 24 - 25 hrs.

All the data presented here give further support to the authors' direct contamination theory for accounting for the pathway of contamination when the fish survives in the water area where the fission products exist in the free state.

SUMMARY

Studies have been made of the direct uptake of Sr^{90} (Y^{90}), Y^{91} and Zr^{95} (Nb^{95}) from fresh water and from sea water, of their distribution in various organs, and further of the excretion pathway. The uptake of I^{131} by carp and goldfish has also been studied. The results can be summarized as follows:

1. It has been shown that the presence of high radioactivity in the alimentary tract of the fish does not necessarily support the food rank hypothesis for the pathway of contamination with radioisotope.

2. Strontium and yttrium behaved quite differently in their uptake and distribution patterns in eel.

3. Zr^{95} (Nb^{95}) was uptaken by eel mainly through the gills. If intramuscularly administered, the internal organs such as spleen and kidney showed the activity higher than that of the hard tissues.

4. I^{131} was found to be uptaken all over the surface of the goldfish and turned over quite rapidly.

REFERENCES

(1) Donaldson, L.R., 1950, *AECD*, **3446**, U.S. Atomic Energy Commission.

———, 1955, *Report on the Effect of Radiation Around Bikini Area (1955)*. The investigation division of the Fishery Agency, Ministry of Agriculture (Japan).

(2) Smith, H.W., 1930, *Am. J. Physiol.*, **93**: 480-505.

(3) Tomiyama, T., 1954, *Kagaku Asahi.*

(4) Tomiyama, T., Ishio, S. and Kobayashi, K., 1956, Research in the Effects and Influences of the Nuclear Bomb Test Explosions, *Japan Society for the Promotion of Science*, 1152-6.

(5) ———, 1956, *ibid*, 1163-7.

(6) Tomiyama, T., Kobayashi, K. and Ishio, S., 1956, *ibid*, 1181-7.

(7) ———, 1956, *ibid*, 1195-1200.

THE UPTAKE OF RADIOACTIVE WASTES BY BENTHIC ORGANISMS

DECOURCEY MARTIN, JR.

University of California, Scripps Institution of Oceanography, La Jolla, California,

The increasing utilization of nuclear energy for industrial, medical, and research purposes may be expected to exponentially increase the yearly output of radioactive waste products. If the amount of waste is sufficiently large, then detectable radioactive contamination will eventually find its way into living organisms. No means of absolutely containing radioactive substances has yet been devised. The safe disposal of the radioactive waste products should be considered to be one of the major problems of the utilization of nuclear power.

The purpose of this paper is to present one study of a potential method of oceanic waste disposal. At the present time, the oceans are considered to be the most feasible repository of low level radioactive waste products by maritime nations. One method of disposal used by the United States Navy, the Atomic Energy Commission, and the University of California Radiation Laboratory is to encase millicurie amounts of radioactive wastes in concrete filled, steel 55 gallon drums which are dumped in 1,000 fathoms of water off the California coast. A preliminary radiological survey of the California disposal areas in April, 1957, showed no detectable indication of artificial contamination originating from the concrete containers, although recent fallout was detected in surface organisms (Faughn, *et. al.*, Proc. Ninth Pac. Sci. Congr. **16**: 152, 1958).

In the event of the disintegration of the concrete containers or the leaching of the radioactive materials by the sea water, it would be desirable to trace the movements of the contaminants to some final deposition or equilibrium system.

During the months of August and September of 1956, the author participated in an equatorial Pacific cruise aboard the University of California research vessel *Horizon.* Measurements were made of the radioactivity of the sea water at various depths, of the zooplankton and phytoplankton, and of the pelagic sediments along a track extending from 11° N. to 11° S. along the 164° E. and 157° E. meridians. Sediments and biological specimens were also collected on the return track through the Marshall Islands to Hawaii. Radioactive contamination from the 1956 series of nuclear tests at the Pacific Proving Grounds was detected in the water and plankton along the entire Equapac track. The surface of the bottom sediments collected north of the Equator showed the presence of artificial radioactivity. Table 1 shows the radioisotopes present in a sample of the water, the zooplankton, and two cores taken along the northern portion of the Equapac cruise.

The radioactivity of the unsorted zooplankton is 500 to 10,000 times greater than that of an equal weight of the surface water. It is interesting to note the presence of Zn^{65}, Co^{57}, Co^{58} and Co^{60} in the plankton. None of these isotopes are orinarily produced by the fission process. The bottom sediments taken north of the Equator showed the presence of Ru^{106} with traces of cobalt and zinc. The most active sample was collected at 11° 44′ N., 166° 13.5′ E. The upper surface of the core assayed 151 μμc Ru^{106} per square centimeter. The absence of Ru^{103} indicates that the contamination is several years old and, therefore, from a different source than the contamination of the surface organisms. No artificial radioactivity was detected in the sediments south of the Equator although radioisotopes were detected in the surface waters and plankton.

The presence of long lived ruthenium and zinc on the ocean floor indicates that some process must be carrying some of the fission products into the sediments. The high uptake of cobalt and zinc by the surface zooplankton suggests that biological concentration plays an intermediate role in the final deposition of the radioactive waste products.

A laboratory experiment was conducted to determine possible uptake or fixation of radioactive waste products by one representative order of benthic organism. A culture of the benthic foraminifer, *Discorbis floridana*, was supplied and nurtured by Mr. John S. Bradshaw of the Scripps Institution of Oceanography. The culture was divided into two parts and each portion transferred to a 50 milliliter sea water medium containing several common laboratory radioactive waste products. The radioactive sea water was prepared from an accumulation of wastes from previous

experiments. The hydroxide and chloride precipitates of the radioelements were allowed to remain in contact with two liters of sea water for a one year period. 100 milliliters of the resulting solution was withdrawn and filtered through a sintered glass filter.

The radioactive foraminiferal cultures were nurtured for 50 days after which time the organisms were filtered and washed with sea water on a 200 mesh sieve. The organisms were dried, weighed, and assayed with a NaI (Tl) scintillation counter and single channel gamma energy differential pulse height analyzer, and with a beta scintillation counter.

Table 2 shows the results of culturing *Discorbis floridana* in a mixture of radioactive wastes. The ability of this organism, which is found in near shore sediments, to remove various isotopes from the surrounding waters is clearly shown. Those isotopes which would be most insoluble at the pH of sea water, Zr^{95} and Ru^{106}, are almost completly removed from the culture. The above experiment does not differentiate between the metabolism and the surface adsorption of the elements. However, washing with uncontaminated sea water did not remove any detectable amount of the radioelements.

Cesium and strontium which are soluble in sea water are almost untouched by the foraminifers. The abundance of potassium, which is biologically similar to cesium, to the extent of 388 mg/l and the presence of natural strontium as 13 mg/l may explain the absence of the radioactive Cs^{137} and Sr^{90} in the organisms. The radioisotopes are diluted by the natural isotopes.

Radioisotopes of the trace elements in the sea water, on the other hand, may be highly concentrated in certain organisms. Zinc concentration in sea water is about 5×10^{-3} mg/l. The cobalt concentration is about 5×10^{-4} mg/l. If these elements are required for growth, an organism may absorb a relatively large percentage of the radioisotopes of the same trace elements.

In the equatorial Pacific, radioactive isotopes were found in the surface water and in the zooplankton. Ru^{106}, Zn^{65}, and Co^{60} appeared to be concentrated in the pelagic sediments. A benthic foraminifer, *Discorbis floridana* was cultured in a radioactive medium and was found to concentrate Zr^{95}, Ru^{106}, Zn^{65}, and Co^{60}. This organism did not concentrate Sb^{125}, Cs^{137}, or Sr^{90}. In the event of leakage of packaged radioisotopes buried in deep sea sediments, some elements such as zirconium, ruthenium, cobalt, and zinc may be expected to be absorbed and concentrated in the sediments by some benthic organisms. Other elements such as cesium and strontium will not be fixed in the sediments, but instead will probably be dispersed throughout the oceans.

Table 1.
Radiochemical and gamma energy spectrum analysis of Equapac samples.
1 June 1957

Isotope	Surface water Station 42 11°N. 158°E. 29 Aug. 56 μμc/liter	Zooplankton Station 42 11°N. 158°E. 29 Aug. 56 μμc/g wet	Core No. 7 11° 44′ N. 166° 13′ E. 4 Sept. 56 μμc/cm²	Core No. 5 00°03′ N. 157° E. 25 Aug. 56 μμc/cm²
Mn^{54}	3.14	2.3	—	—
Co^{57}	.34	45.4	—	—
Co^{58}	.2	28	—	—
Co^{60}	*n.d.*	7.4	1.8	—
Zn^{65}	8.3	82	7.3	—
$Sr^{89} + Sr^{90}$	—	1.2	—	—
Zr^{95}	5.3	8.0	—	—
Ru^{103}	6.4	4.2	0	0
Ru^{106}	26.4	14.7	151	0.5
Sb^{125}	7.9	*n.d.*	—	—
Cs^{137}	7.5	*n.d.*	—	—
Ce^{144}	10.7	79.5	189	—
K^{40}	264	—	1.5 μμc/g	5.6 μμc/g dry
Ra^{226}	—	—	18 μμc/g	6.8 μμc/g dry

Table 2.
Uptake of radioactive waste products by the benthic Foraminifera, *Discorbis floridana*.
26 May 1956

Isotope	Sea Water μμc/culture	Sea Water μμc/ml	Forams μμc/13 mg	Forams μμc/g	Percent fixation of total activity in organisms after fifty days	Concentration factor μμc/g Foram. / μμc/ml water
Co^{60}	5,600	112	475	36,500	8.5%	326
Zn^{65}	6,000	120	780	60,000	13	500
Zr^{95}	3,750	75	3,300	254,000	88	3,400
Ru^{106}	13,500	270	9,700	747,000	72	2,800
Sb^{125}	6,250	125	75	5,770	1.2	46
Cs^{137}	12,500	250	0	0	0	0
Sr^{90}	10,000	200	24	1,850	0.24	9

APPROXIMATE DOSAGES CLOSE TO SUBMERGED RADIOACTIVE LAYERS OF BIOLOGICAL INTEREST

THEODORE R. FOLSOM

Scripps Institution of Oceanography, University of California, La Jolla, California, U.S.A.

In nature, radioactivity frequently is found concentrated in thin layers, and it is often of interest to study the flux or dose rate at points close to such layers. Unfortunately, laminar radioactive sources produce results which are not easy to predict by means of intuition alone, but require mathematical and graphical aids that are not commonly available. Many laminar radioactive accumulations can be found adjacent to interacting marine biospheres and the amounts of activity in some of these have been influenced by, or even have been created by the recent introduction into the sea of artificial radioactivity. Studies of the concentrating ability of marine algae have been going on for several years at the Scripps Institution and recently, special attention has been turned to the radioactivity associated with a certain giant thin bladed marine algae, the kelp *Macrocystis pyrifera*, which is a notable activity concentrator. For interpreting this radiological system, some graphical solutions have been carried out and will be described here. It is believed the method, which pretends only to give a convenient approximate solution to the radiological problem, will be of particular interest to marine biologists interested in estimating the rough magnitude of underwater dose to certain small organisms.

Radiation Near Submerged Algae Blades

A submerged sea weed behaves toward radiation as a scatterer and as an absorber, almost as does the water surrounding it; this simplifies the problem somewhat. But complications arise from the fact that algae commonly are strong concentrators of natural activities, particularly radiopotassium, and these exterior surfaces may be strongly contaminated by fallout activity. Nevertheless the close neighborhood may be the habitat of living cells and small organisms of interest, and one, therefore, must consider not only radioactive sources distributed through layers having a measurable thickness, but also must attempt to estimate the radiation at points lying very near to extremely thin finite concentrations on exterior surfaces.

At the top of Fig. 1 is sketched the source distributions to be considered. To point P near the sea-kelp interface come penetrating gamma rays from long distances r_2, and from much smaller ranges r_1, come beta particles. The usual *Macrocystis* blade is about 1/2 mm. thick. This is far smaller than the maximum range of beta particles from several nuclides known to be involved, and the question arises as to whether the kelp blade acts like a semi-infinite beta source or like something more complex. It was decided to attempt a general solution under the assumption that beta attenuation could be described, at least approximately, in the usual exponential manner.

Thin Plane Layers

One well known solution for the flux in the neighborhood of a plane distribution of sources is frequently resorted to. Here it will be discussed first in order to illustrate some of the properties of the peculiar integral function needed for numerical solutions. The numerical solution of the simple problem outlined at the center of Fig. 1 requires a suitable table of the definite integral,

$$Ei(-X) = -\int_x^\infty \frac{e^{-t}}{t}\,dt$$

This is called the negative exponential integral. It unfortunately has many annoying habits—a common one being reluctance to appear within the range of the tables at hand. Moreover, it is not easy for one to visualize the trend of this integral. This is aggravated by a widely circulated graph that is so plotted that one is likely to conclude, that for small values the integral rushes rapidly to negative infinity. Such a conclusion is disasterous. It will be shown later that this would predict that an infinitely large flux must occur near a plane source having finite surface activity.

Actually it can be shown that this function $Ei(-X)$ has a very slow trend in the region pertaining to the computing of beta and gamma fluxes very close to surface activities. In Fig. 2 has been plotted the negative of this function over the full

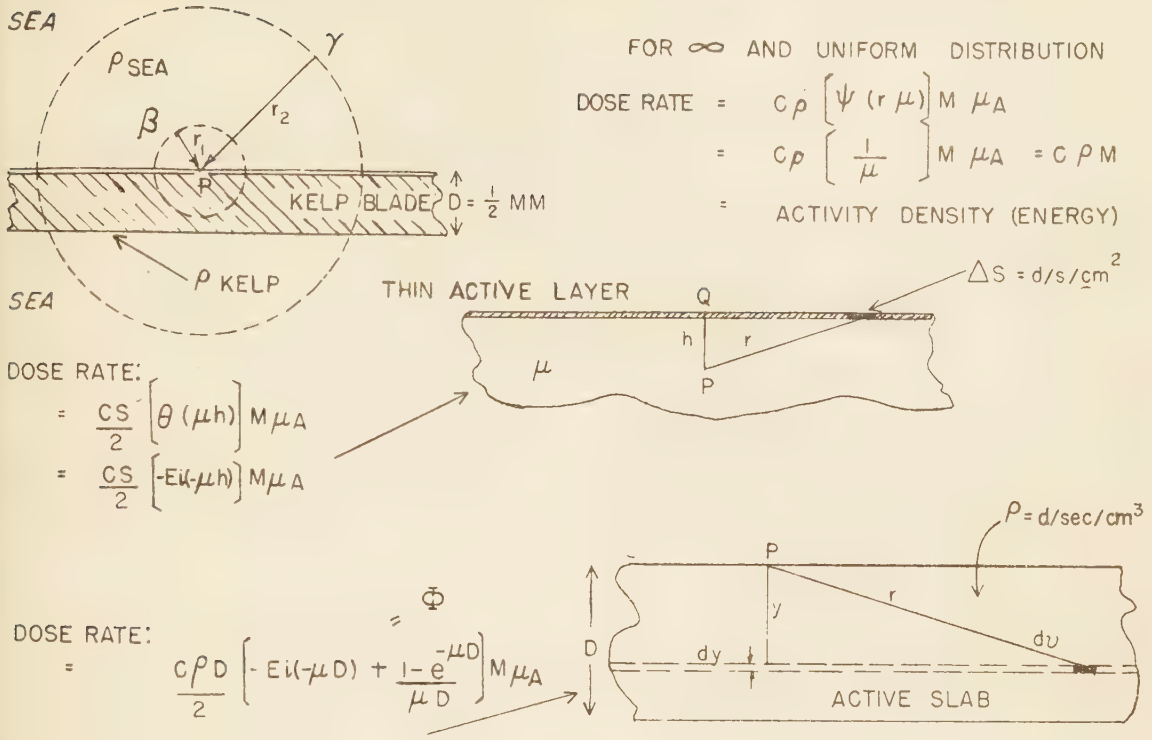


Fig. 1.—

region generally used in this work. On the curve, it will be noted that even when $X = 10^{-8}$ the value of the function is only 17.8— which is far distant from infinity.

The formula for dose rate at point P near the plane source is given at the left center of Fig. 1. The argument μh, for a given radiation depends only upon the distance h, so dose rate (predicted approximately by this formula) has been evaluated in Fig. 3 using four separate attenuations corresponding approximately to those of the beta and gamma radiations found in submerged sea weeds. The value of the function $Ei\,(-\mu h)$ is seen to vary by only two orders of magnitude when the distance h varies over the extreme range, wherein interest lies. For example, beta doses might be of most interest at points between 0.1 cm. (order of blade thickness) and 0.001 cm. (order of cell radius), and it can be seen that over this range, this peculiar function changes less than two orders of magnitude. The behavior in connection with gamma rays is similar.

Dose From Thick Radioactive Laminae*

The mathematical procedure for avoiding infinite field values near source points used above, need not be resorted to when the source is a thick slab where volume densities can be used. For example, consider the point P at the slab source in the lower right hand corner of Fig. 1. The flux at P is obviously the sum of the individual contributions from thin laminae, and for this geometry the solution for dose rate is written at the left of the picture.

By comparing this dose rate formula with that relating to the thin lamina and also with that relating to the still simpler problem involving an infinite-uniform distribution, it can be seen that the function defined as:

$$\phi\,(-\mu D = -Ei\,(-\mu D) + \frac{1-e^{-\mu D}}{\mu D}$$

is a characteristic of this thick slab source in the same way that the exponential function $(Ei{-}\mu D)$ is characteristic to the thin-layer problem.

It can be mentioned in passing that in the simple uniform-infinite source problem, the function $1/\mu$ plays the same part. (See formula at top of Fig. 1).

$\phi\ (-\mu D)$, as just defined, has been plotted in Fig. 4; it is evidently a slowly varying function in the range of present interest. For further emphasizing this slow trend, Fig. 5 has been computed using the coefficients for gamma and beta attenuation believed best suited to describe the gamma and beta radiations coming from natural radiopotassium and from fallout contaminations appearing in recent months in the sea.

$\phi\ (-\mu D)$, for any definite value of μ, is a geometrical factor which can be applied to slabs of submerged biological material, and it can be seen that this factor varies less than two orders of magnitude when the slab thickness D varies from a few centimeters down to the dimensions of living cells. Fig. 4 is a convenient compilation of data, perhaps as useful as the exponential integral.

Approximate Dose Rate near a Submerged Kelp Blade

In conclusion, a numerical example will be given relating to the point P on the submerged blade of kelp shown in the upper left picture of Fig. 1. In Table 1 is listed separately the values obtained by use of the formulae given for the various likely radioactivities present. This table was computed as simply as possible, using only rough estimates of the effective attenuation coefficients. Numerical values having two significant figures are not warranted, but this permits a better comparison of the trend of the functions which this example was intended to exhibit.

It can be concluded, nevertheless, that there is some evidence here that fallout contributed quite substantially to the total radioactive burden carried by small organisms in this particular biosphere.

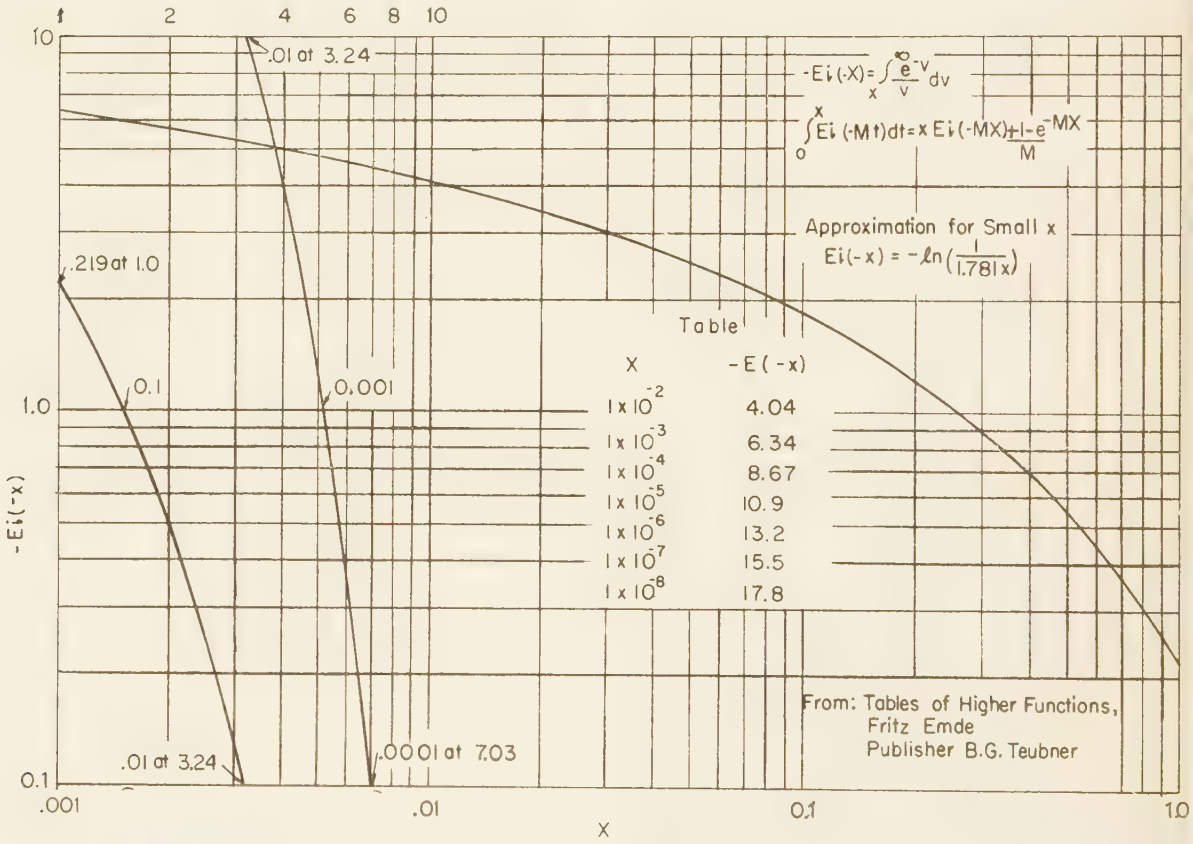


Fig. 2.—Exponential integral function (for small numbers).

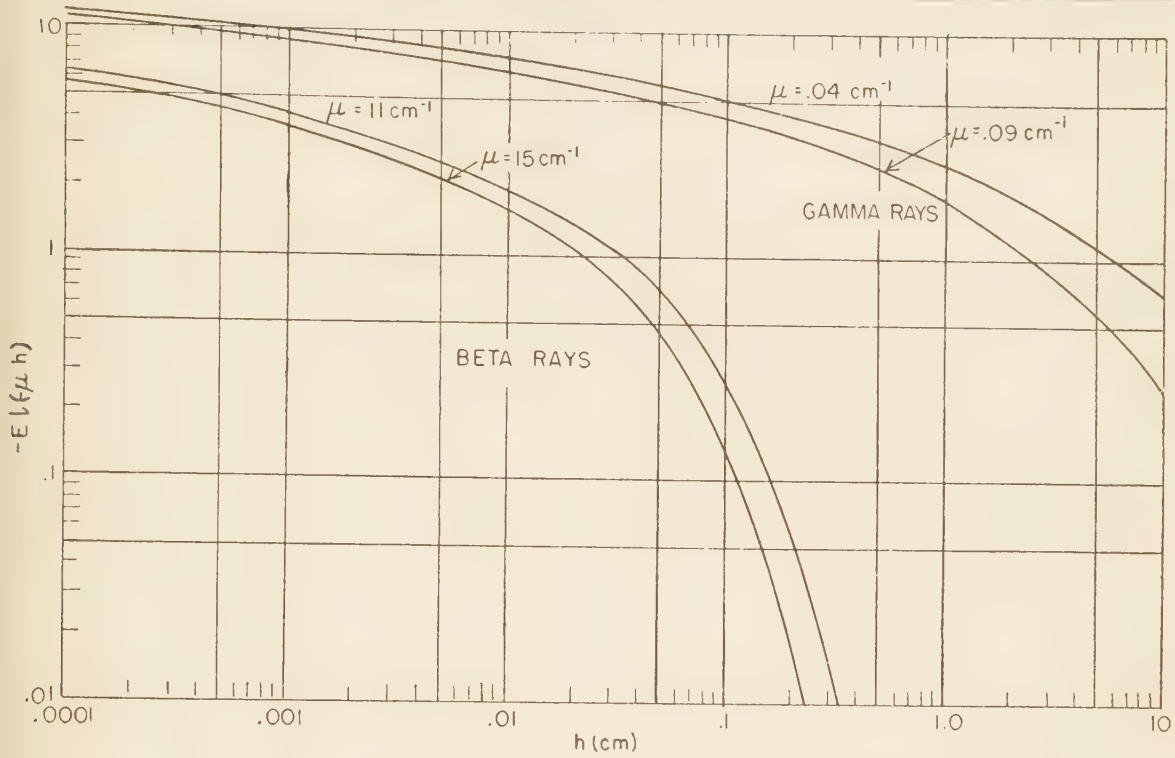


Fig. 3.— Approximate trend of flux due to *thin* active layers.

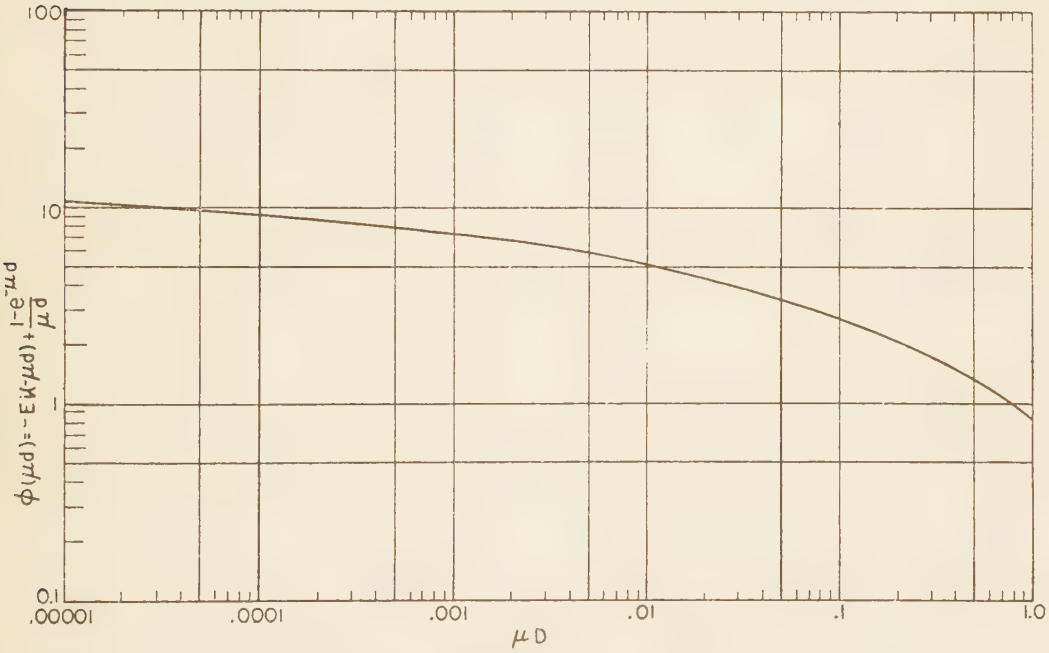


Fig. 4.— Geometrical coefficient for radioactive flux from slabs.

Table 1.*

Estimate of dose rate contributions at a point near the surface of a kelp blade.

	mrads/year
I. Natural Sea Activity (only potassium considered)	
Gamma dose rate from surrounding sea	.86
Beta dose rate from sea on one side	1.4
II. Natural Kelp Activity (only potassium considered)	
Gamma dose rate from blade 1/2 mm. thick	.18
Beta dose rate from K distributed uniformly through blade	29.
III. Activity Due to Fallout	
A. Assuming uniform distribution through blade	
Gamma dose rate	.21
Beta dose rate	7.6
B. Assuming F.O. activity is in thin layer on surface	
1. Dose at most remote point, i.e., h = .05 cm. = blade thickness	
Gamma dose rate	.21
Beta dose rate	2.5
2. Dose at distance of cell radius, i.e., h = .001 cm.	
Gamma dose rate	.29
Beta dose rate	28.

**Explanatory Notes*

1) Numerical values perhaps should be rounded to one significant figure except for exhibiting the behavior of the mathematical functions. For grams, seconds, cm., mev., and milirads/year constant C on Fig. 1 = 500.

2) For Potassium was taken:

photon energy 1.5 mev.
true absorbtion (and attenuation) $\mu_A = \mu = .04$
beta maximum 1.3 mev.
beta absorbtion $\mu = 11$ cm^{-1}
beta mean energy $M = 5$ mev.

For sea was taken (considering only K):

gamma activity 1.13×10^{-3} d/s/g.
beta acitivity 1.1×10^{-2} d/s/g.

For kelp (*Macrocystis* from La Jolla) was taken:

K gamma activity 0.034 d/s/g.
F.O. gamma activity .1 d/s/g. (measured)
F.O. true absorbtion μ_A also gamma at tenuation $\mu = .04$
K beta activity .33 d/s/g.
F.O. beta activity .1 d/s/g. (estimated)
F.O. attenuation coefficient $\mu = 15$ cm^{-1}
F.O. mean beta energy .4 mev.

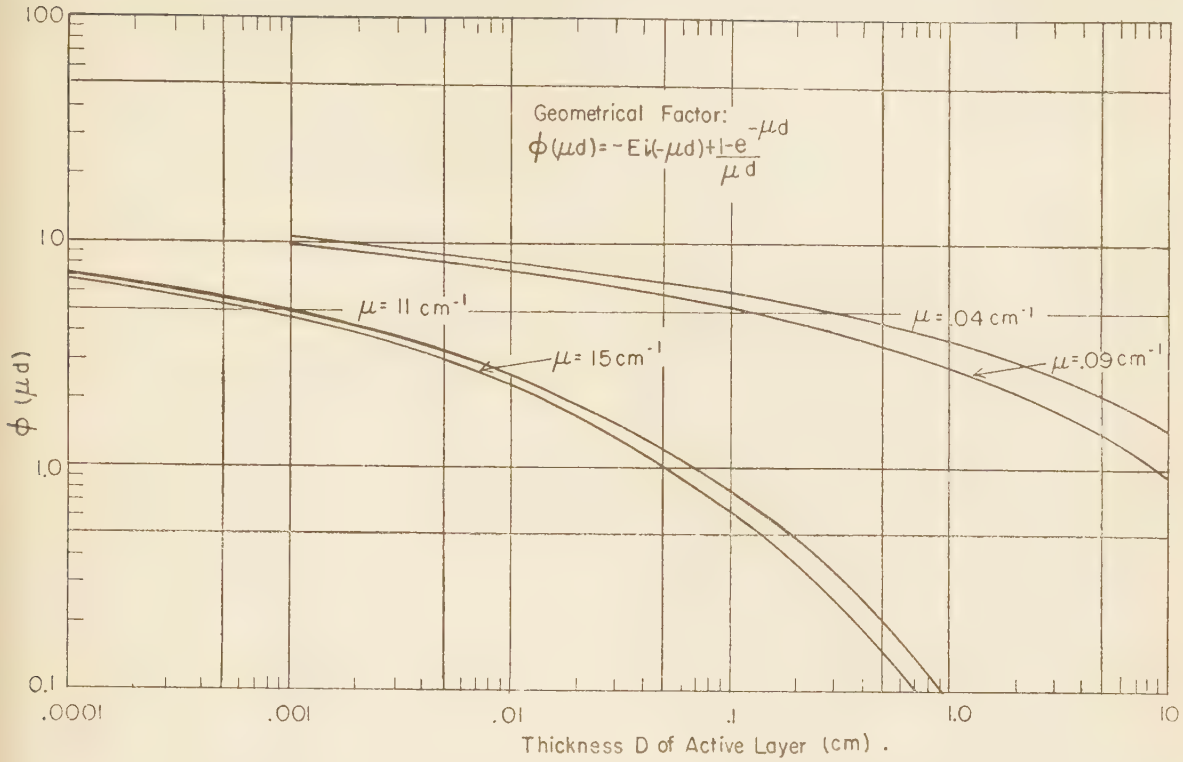


Fig. 5. — Approximate trend of flux due to *thick* active layers.

COMPARISON OF RADIOACTIVE DOSAGE FROM POTASSIUM WITH ESTIMATED DOSAGES FROM URANIUM AND RADIUM IN MARINE BIOSPHERES†

THEODORE R. FOLSOM

Scripps Institution of Oceanography, University of California, La Jolla, California, U.S.A.

In recent years artificial radioactivity has appeared in certain marine biospheres in amounts sufficient to at least double the previous radioactive dose due to natural activities *(1)*. Gamma and beta analyses frequently show that radiopotassium is an outstanding source of natural radiation, but, until the part played by alpha particles has been evaluated, it is not safe to conclude that members of the radium and thorium series do not contribute substantially to the dose of marine biological tissues.

An estimate will be given here of the magnitude of the doses arising from the small amounts of radium and uranium reported to be accumulated in certain sea weeds. These doses will be compared with that caused by radiopotassium. The radium dosages will be estimated from total energy lost during radioactive disintegration.

Potassium Activity in Sea Water *(4)*

Gamma Activity

Take gammas/gram K/sec = 3.9,
and grams K/ml = 3.8×10^{-4},
and mev/gamma = 1.46,
then the gamma activity in sea is = .0022 mev/sec/gram, approximately.

Beta Activity

Take betas/gram K/sec. = 27,
and grams K/ml = 3.8×10^{-4},
and average mev/beta = .5,
then the beta activity in sea water is = .0051 mev/sec/gram, approximately.

Potassium Activity in Kelp (*Macrocystis* from La Jolla)

Gamma Activity

Take gammas/gram K/sec = 3.9,
and grams K/gram wet kelp = .01,
and mev/gamma = 1.46,
then gamma activity in kelp is = .06 mev/sec/gram, approximately.

Beta Activity in Kelp

Take betas/gram K/sec = 27,
and grams K/gram wet kelp = .01,
and mean mev/beta = .5,
then beta activity is = .14 mev/sec/gram, approximately.

Radium and Uranium Activity from Energy Levels

Computation of total potentially-ionizing activity

Take mass of	$92U^{238}$	= 238.13232
	$88Ra^{226}$	= 226.10309
(RaD)	$82Pb^{206}$	= 206.0419
	$2He^{4}$	= 4.00389

(One mass unit = 931.4 mev.)
(One mev. = 3.91×10^{-14} small calory)

Take 3 alphas between U and Ra
and 5 alphas between Ra and Pb^{206}

Take the sum of the maxima beta energies per primary disintegration between

U^{238} - Pb^{206} = 6.3 mev., approximately,
Ra^{226} - Pb^{214} (RaB) = 0 mev., approximately,
Ra^{214} - Pb^{214} (RaC) = .70 mev., approximately,
RaC - Pb^{210} (RaD) = 1.70 mev., approximately,
Pb^{210} - Bi^{210} = .02 mev., approximately,
Bi^{210} - Pb^{206} (Lead) = 1.17 mev., approximately.

Take the energy lost to the neutrino (i.e., not causing heat or ionization) to be roughly = 2/3 the max. beta energies, that is 2/3 (3.7) = 2.4 mev., *(5)*. Then one can estimate the potentially ionizing activity between,

U^{238} - Pb^{206} = 47.9 mev/primary disintegration
Ra^{226} - Pb^{206} = 33.4 ,, ,, ,,
RaD - Lead = 5.9 ,, ,, ,,
Ra^{226} - RaD = 27.5 ,, ,, ,,

† Contribution from the Scripps Institution of Oceanography, New Series No. 000.

Computation of Radium and Uranium Gamma Disintegration Energies

Taking the approximate gamma energy per primary disintegration (2)

U^{238} - Ra^{226} = 0.06 gammas of 0.19 mev. = 1.1×10^{-4} mev/dis

Ra^{226} - RaD = 11 gammas with total = 1.9

RaD (22 yrs) - Lead = 0.81 gammas of 0.046 mev. = 0.037 mev/dis

Ra^{238} - Lead = 1.94 mev/dis

Concentrations of Radium, Uranium, and Potassium in Sea Water and in Seaweeds

Potassium in sea water	3.8×10^{-4} g K/ml
Potassium in seaweed[1]	.01 g K/ml
Radium in surface sea water *(4)*	1×10^{-16} g Ra/ml
Radium in seaweed, (assumed consistent with assays of Wiesner *(6)* and consistent with rough gamma measurements at S.I.O.)	1×10^{-13} g Ra/ml

Computation of Activities

Disintegration constants (Birch, F., p. 151, and *4*)

For K = 1.8×10^{-17} per second
For U = 4.9×10^{-18} per second
Ra = 1.4×10^{-11} „ „

Potassium Activities

Gamma activity in sea water
(.0013) $(3.8 \times 10^{-4}) = 0.5 \times 10^{-6}$ mev/sec/ml
Beta activity in sea water
(.0046) $(3.8 \times 10^{-4}) = 1.7 \times 10^{-6}$ „
Gamma activity in seaweed
(.0013) (.01) = 1.3×10^{-4} „
Beta activity in seaweed
(.0046) (.01) = 4.6×10^{-4} „

Radium Activities

Because the life of seaweed is short (about 1 year usually), the activity below RaD (22 years) will be ignored; it would only contribute about 2% to the total dose even if equilibrium were attained.

[1] Folsom, T.R. and Martin, DeC., measured by gamma analysis of La Jolla *Macrocystis* blades, stipes have double this concentration (1957).

Total Radium activity (Ra - Lead) in sea water
(33.4) (1×10^{-16}) (6×10^{23}) $(1.4 \times 10^{-11})/226$
$= 1.24 \times 10^{-4} = .00012$ mev/sec/ml

Total radium activity (Ra - RaD) in seaweed
(27.5) (1×10^{-13}) (6×10^{23}) $(1.4 \times 10^{-11})/226$
$= 1.0 \times 10^{-1}$ mev/sec/ml.

Estimate of Uranium Activity for Comparison

Uranium in surface water is reported variously, Petterson *(4)* gives 1×10^{-9} gm/ml—more recently values are about three times as high; its concentration in kelp has not been measured yet at S.I.O. The total ionizing activity corresponding to the reported concentration of uranium in sea water would be approximately, if all daughter products were included, if the new values were used,

(47.9) (3×10^{-9}) (6×10^{23}) (4.9×10^{-18}) (238)
$= (17.7 \times 10^{-4})$ mev/sec/ml.

However, uranium is not in equilibrium with all its daughters in the sea; it is reported that only about 4% contributes to the radium of the sea, the rest is deposited in the sediments *(3)*.

Application to Two Typical Radiobiospheres

Specific activity is numerically equivalent to dosage absorbed whenever the activity is distributed uniformly within a uniform scatterer—that is uniform over what corresponds to several times the average distance a photon or particle travels before being absorbed. In open sea water at a distance of the order of meters from any discontinuity, the dose received by a small, watery organism is numerically equal to the specific activity of the sea water. This computation is not so simple for the case where gamma activity is concentrated in a thin lamina such as a leaf of seaweed; here the geometry of the leaf must be specified, and the pertinent factor, $\phi(\mu D)$, has been reported in some details elsewhere *(1)*.

It can be shown *(1)* that potassium beta rays have effective ranges short enough to permit one to consider thin organic laminae (such as kelp leaves) containing radioactivity as approximating semi-infinite sources; and at points on the interior of a leaf about 1 mm. thick, the beta and, of course alpha particles also, are absorbed essentially as from an infinite source. With this in mind the dosage effects of radium and potassium activities can be compared in simple tables. Tables 1 and 2 compare the effect of the short ranged particles separately from the doses arising from the major hard gamma photons.

Table 1.

Estimated gamma activity in mev/sec/ml. (*mrads/year assuming infinite geometry in parentheses*)

	Sea water	Seaweed
Potassium	2.2×10^{-3} (1.0)	60×10^{-3} (30)
Radium	7.2×10^{-6} (.004)	7.0×10^{-3} (7)

Table 2.

Estimated energy from short ranged particles in mev/sec/ml. (*mrads/year in parentheses*) *

	Sea water	Seaweed
Potassium (betas)	5.1×10^{-3} (2.6)	140×10^{-3} (70)
Radium (total energy-gammas)	$.11\times10^{-3}$ (.055)	93×10^{-3} (47)

* About 23% of the total uranium energy capable of ionizing resides above thorium-230; this position alone should give rise to particulate dosage in sea water of about 0.4×10^{-3} mev/sec/ml,, which is even larger than that contributed by radium.

Conversion to Common Dosage Unit, Mrad/year

The dose rate unit, mrad/year equals 100 ergs absorbed per year per gram of water. One mev/sec/gram of absorbed energy is equal to 503 mrads/year. In Tables 1 and 2 are given in parentheses the dose rates in mrads/year which would be delivered if the sources were widely distributed.

Conclusion

It is apparent that radium, and perhaps also uranium and thorium, in amounts reported in seaweeds and in sea water can contribute appreciably to the total radiation dose to certain organisms living in the open sea and within certain seaweeds.

This should be considered by those concerned with mutations of microorganisms and of organisms having natural radioactivity distributed through gonadal tissue.

REFERENCES

(1) Folsom, T.R., 1959, Approximate Dosages Close to Submerged Radioactive Layers of Biological Interest, *Proc. Ninth Pac. Sci. Congr.*, **16**: 170.

(2) Freedlander, G. and Kennedy, J.W., 1949, Introduction to Radio-chemistry. New York: John Wiley & Sons, p. 12.

(3) Koide, Minoru, 1957, Chemistry Division of Marine Chemistry, Scripps Institution of Oceanography (personal communication).

(4) Pettersson, H., 1954, *Nuclear Geology*. New York: John Wiley & Sons, p. 116.

(5) Stern, M.O., 1949, The Masses of the Heavy Isotopes, *Revs. Mod. Phys.* **21**: 316-321.

(6) Wiesner, R., 1939, Determination of the Radium Content of Algae, *Silzber, Akud, Wiss. Wien, mattr. -nuluru. Kl., Aot.*, **2a**: 147, 521-528.

Symposium: *Physical and Chemical Oceanography*

PRECIPITATION, EVAPORATION, AND ENERGY EXCHANGE AT THE SURFACE OF THE SOUTHEAST ASIAN WATERS†

KLAUS WYRTKI

Institute for Marine Research, Djakarta, Indonesia.

(Abstract)

In order to study the factors influencing the annual variation of the surface salinity and temperature in the Southeast Asian waters, precipitation, evaporation, and energy exchange at the surface have been calculated. For 15 regions, into which the area has been subdivided, the average annual values of the climatic factors have been determined. These are the temperature of the air, of the water, the relative humidity, the wind velocity, the radiation, and the cloudiness. From these values the evaporation has been calculated by means of Sverdrup's formula. The annual variation of the rainfall has been obtained from an earlier paper by the author. The distribution of the difference between precipitation and evaporation shows that the evaporation dominates during the northeast monsoon over the China Sea, and during the southeast monsoon over the regions south of the Equator. In the vicinity of the Equator the rainfall always exceeds the evaporation.

In the calculation of incoming and backradiation, allowances have been made for cloudiness. Their difference gives the heat available for evaporation, heating of the water and the atmosphere, as well as for advective processes. The heat used for evaporation is the mean factor in the energy balance. Sometimes it exceeds the surplus of radiation, which causes a cooling of the water. In the northern China Sea and in the regions south of the Equator, the calculated deficit of the energy is in agreement with the observed decrease in temperature of the surface layer during the dry season. The energy made available for the heating of the water is given off by advective processes in horizontal and vertical directions.

Using these results, the annual variation in the surface salinity and temperature within the 15 regions can be explained, and it can be shown how much they are influenced by the atmosphere or by advective processes.

DISCUSSION

K. HIDAKA: How was constant K computed?

K. WYRTKI: By equating total evaporation with the sum of total precipitation plus run-off over the earth.

T.R. FOLSOM: Mixing rates have been measured by Scripps' workers by measuring downward progress of radioactive fallout of the sea. Also radioactive layers found within the thermocline have been observed to remain stratified in layers a few meters thick for weeks.

K. WYRTKI: Yes, thin stable stratified turbidity layers in the thermocline have been also observed.

Y. MIYAKE: Did you consider vapor pressure changes due to salinity variation?

K. WYRTKI: No, these effects would be too small.

† Published in the *Penjelidikan Laut Di Indonesia* (Marine Research in Indonesia) No. 3: 7 - 40, Djakarta, 1957.

CANADIAN OCEANOGRAPHIC RESEARCH IN THE NORTHEAST PACIFIC OCEAN

A.J. DODIMEAD and J.P. TULLY

Pacific Oceanographic Group, Nanaimo, B.C., Canada.

The region of the Pacific Ocean of primary interest to Canada includes the area north of latitude 40°N. and east of longitude 175°W. This is the ocean habitat of the American and Canadian salmon stocks. Synoptic oceanographic surveys have been carried out in this area during three summers, August, 1955, 1956 and 1957, and one winter, February, 1957. The first survey was "Project Norpac" in which fifteen oceanographic agencies in Japan, the United States, and Canada made coordinated surveys over the whole ocean north of latitude 20°N. The subsequent surveys have been undertaken by the Canadian Government as part of its obligation to the research program of the International North Pacific Fisheries Commission. Each survey required about six weeks sea time and was made during the period of maximum summer, or minimum winter temperatures, when oceanographic conditions were most nearly stable. The properties of the water, the structure, and the currents from the surface to more than 1,000 meters depth and frequently to 2,000 meters were examined.

All these data have been published in Data Records, in the Manuscript Series of the Fisheries Research Board of Canada.

In addition to these surveys, extensive exploratory fishing for Pacific salmon has been carried out, during which oceanographic observations were made from the fishing vessels.

From these data it is now possible to present the principal oceanographic features of this area, the current systems, and the summer and winter variations. No attempt is made to discuss the oceanographic variations that occur from summer to summer. Furthermore, it would be very laborious to review all the data here. This is not necessary since it has been and is being displayed elsewhere *(7)*. It is sufficient to illustrate these discussions with examples from one summer and one winter survey, and comment on the similarities and differences observed in other surveys.

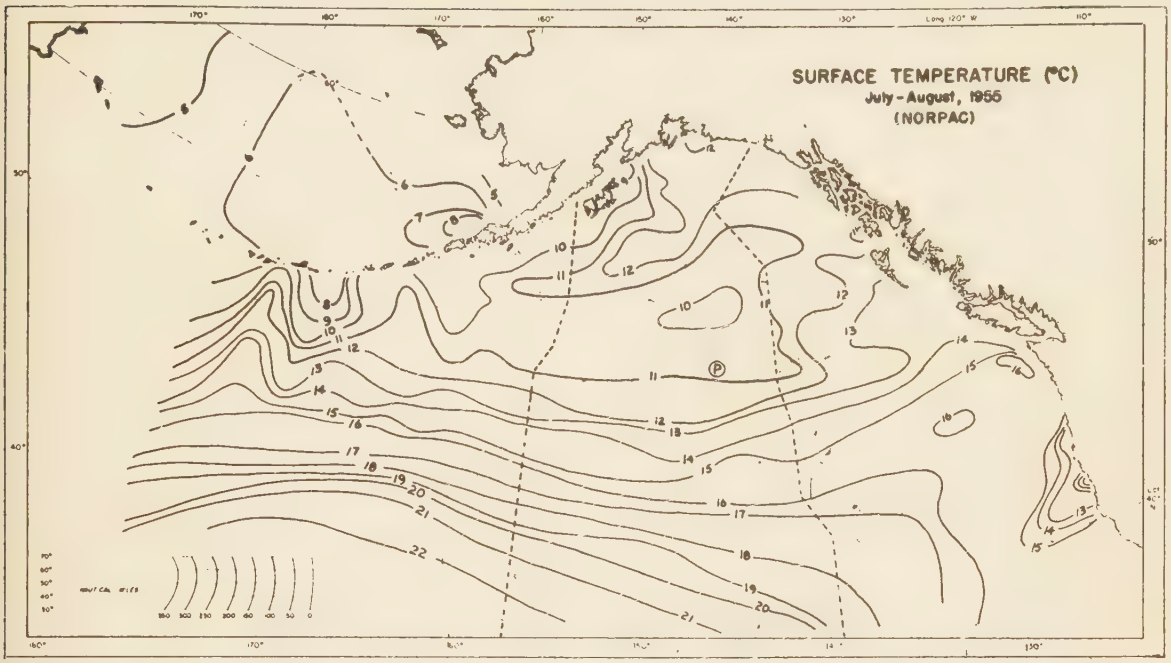
TEMPERATURE

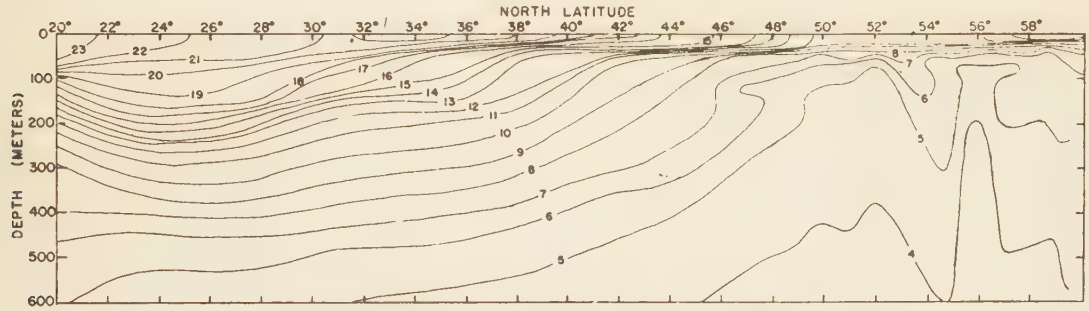
The observed distribution of temperature for August, 1955, over the surface and in south to north vertical sections is shown in Fig. 1. These data show that there is a gradient of temperature from latitude 40°N. in mid-ocean, northward towards the North American Coast. A minimum temperature occurs in the western part of the Gulf of Alaska. From this cold center, the temperatures increase shoreward. South of latitude 40°N., in mid-ocean, there is a central body of warm water.

The longitudinal sections show that the temperatures decrease with depth. There is an upper, warm layer of the order of 50 meters depth. Below this is a well defined thermocline extending to about 100 meters, and then generally a gradual gradient of decreasing temperature. Below the thermocline there are small irregularities in the temperature structure that occur between depths of 120 to 200 meters, the magnitude of the temperature inversions and the depths at which they occur vary within the area. These anomalies occur in the region of the halocline. The temperatures decrease to the northward in the upper layers and in the depths so that the temperature gradient in the thermocline remains nearly constant through the area. In the deep water the isotherms rise toward the surface, going from south to north, and come nearest to the surface in the region of coldest surface water in the Gulf of Alaska. However, the thermocline remains continuous and at constant depth through this cold center, separating the cold surface water from the dome of cold deep water.

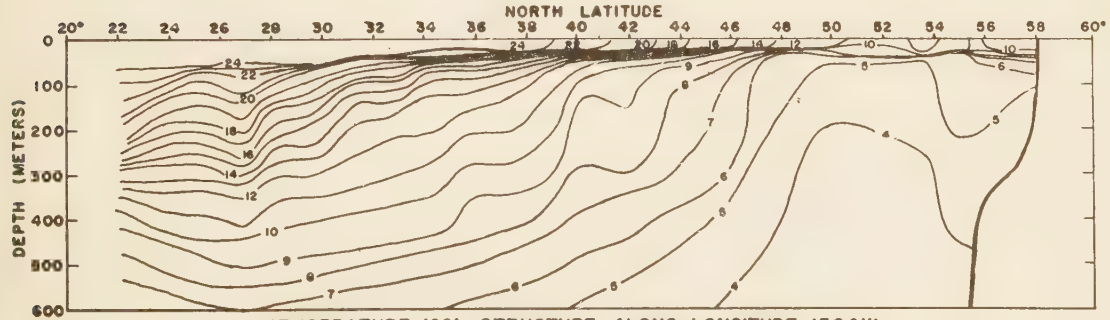
In later years, 1956 and 1957, these principal features persisted. However, as shown in Fig. 2 the cold center moved westward, and the isotherms curved northeastward around the Gulf of Alaska rather than southwestward.

Figure 3 shows the winter data observed in February, 1957. Over the surface (10 meters depth), the configuration of the isotherms was generally similar to those observed in summer. The highest temperatures were at the southern limit of the region surveyed, and the coldest water was in the Gulf of Alaska, south of Kodiak and the Shumigan Islands. It is notable that the winter



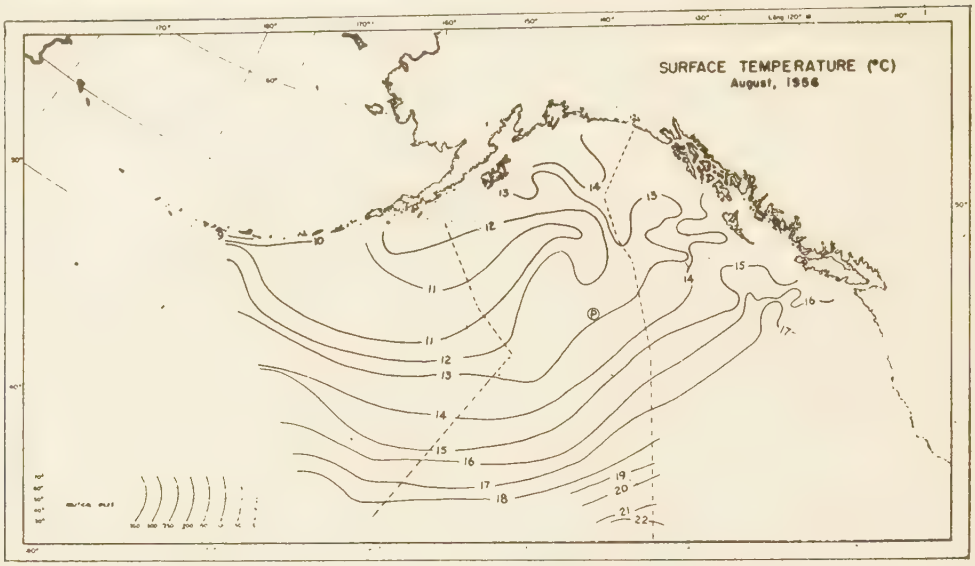


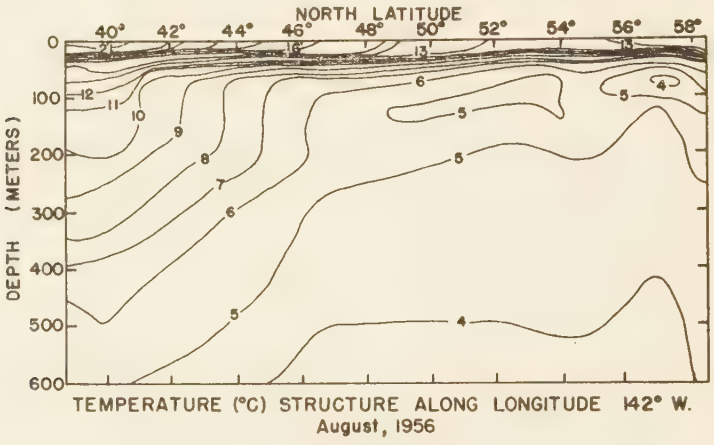
TEMPERATURE (°C) STRUCTURE ALONG LONGITUDE 140° W.
July - August, 1955 (NORPAC)



TEMPERATURE (°C) STRUCTURE ALONG LONGITUDE 156° W
July - August, 1955 (NORPAC)

Fig. 1.—


SURFACE TEMPERATURE (°C)
August, 1956


NORTH LATITUDE
40° 42° 44° 46° 48° 50° 52° 54° 56° 58°
DEPTH (METERS)
0 100 200 300 400 500 600
TEMPERATURE (°C) STRUCTURE ALONG LONGITUDE 142° W.
August, 1956

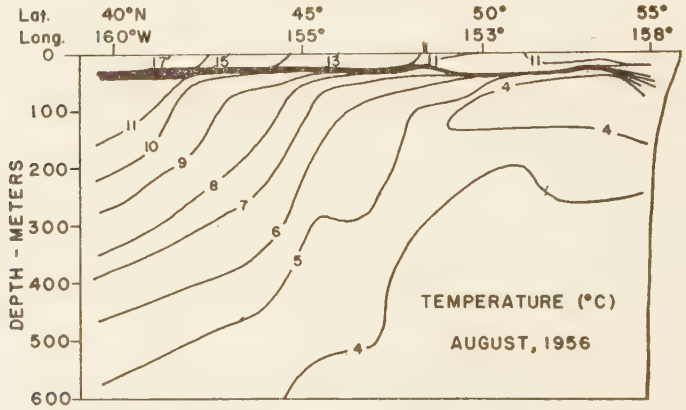

Lat. 40°N 45° 50° 55°
Long. 160°W 155° 153° 158°
DEPTH - METERS
0 100 200 300 400 500 600
TEMPERATURE (°C)
AUGUST, 1956

Fig. 2.—

range of temperature (4° - 11°C.) over the area was almost identical with that observed in summer, from 11° to 18°C. This suggests that the total heating and cooling was very nearly constant over the whole area and amounted to about 7°C.

The longitudinal sections show that there was a south to north gradient in the surface and deep waters, with the coldest region in the Gulf of Alaska. In the area extending about 250 miles offshore, the surface waters were cold. The temperature was isothermal or decreased slightly to a depth of 125 meters. The temperature then increased to a maximum at about 150 to 175 meters, and again decreased regularly with depth. This temperature inversion was stable because it coincided with the halocline. Over the remainder of the area the upper waters were warmer than the deep waters, and the thermocline became pronounced to southward.

Hollister *(1)* examined the daily bathythermograph observations from ocean weather station PAPA (latitude 50° N., longitude 145° W.) through the years 1950 to 1955. From this study a representative diagram of the annual temperature cycle and representative gradients are shown in the upper diagram of Fig. 4. In mid-winter (February-March), the upper waters are isothermal and somewhat colder than the deep waters. Spring warming becomes apparent in April when a thermocline develops at about 50 meters depth. This thermocline becomes more intense and deepens as the warming continues through September. Surface cooling starts in late September and continues through the autumn while the thermocline becomes deeper and less marked until it vanishes in January. The annual temperature range at the surface is seven or more degrees Centigrade. This decreases with depth to 120 meters where the range is less than one degree. These observations were confirmed by Robinson *(3)*. She showed that the temperature cycles and range in all parts of the area were similar to that shown in Hollister's figure. Of course, the absolute values varied according to position.

These data show that the annual temperature cycle is consistently recurrent, the range of seasonal variation is nearly constant over the area, and that the temperatures below the deepest level of the thermocline are nearly constant. It is inferred from this that the depth of the thermocline marks the limit of seasonal heating and cooling, and that the temperature distribution in the deep water is independent of the cycle of the upper zone.

There is no doubt that one of the principal features of these sub-Arctic regions is the annual cycles of heating and cooling. The amount of heat directed toward the sea depends principally on the mean altitude of the sun and the hours of daylight. These vary with latitude and season. The amount of heat reaching the sea is reduced by absorption in the atmosphere, reflection from the sea surface, and cloud cover. The sea loses heat by back radiation, transfer of sensible heat to the atmosphere, and evaporation. These processes were studied in the British Columbia coastal waters by Tabata *(5)* who derived the net heat transfer as shown in the second diagram of Fig. 4.

From the end of March until the end of September, the heating processes are dominant. During the remainder of the year, the waters are being cooled. This corresponds precisely with the observed temperature cycle shown in the first diagram where maximum temperatures occur in September at the end of the heating period, and minimum temperatures occur in late March at the end of the cooling period. This suggests that the heating and cooling of the surface water is primarily a local process.

Figure 5 shows the annual cycle of daily incident energy from the sun through the northern temperate latitudes. During the summer, the incident energy is nearly constant from latitude 40° N. to 60° N., a gradient develops in autumn, reaches a maximum in winter, and degenerates in spring. The summer and winter gradients of incident energy accompany the diagram.

The second pair of diagrams show the average cloud cover over the area in summer and winter *(8)*. Cloud cover absorbs radiant energy at the rate of 7.1 % for each tenth of the sky obscured. Applying this correction to the radiant energy, the average of seasonal insolation over the area was obtained as shown in the third pair of diagrams. This corresponds remarkably with the summer and winter surface isotherms shown in the last two diagrams of the figure. This is further confirmation that heating is primarily determined by insolation, and the cooling factors are relatively constant through the year. It is also apparent that in the absence of a longitudinal heating gradient, as in summer, the cloud cover is a major feature; however, in the winter the cooling processes are dominant, and the cloud cover is a secondary feature.

This analysis has not been completed to determine if the heat content of the upper zone corresponds precisely to the heat budget, or why the

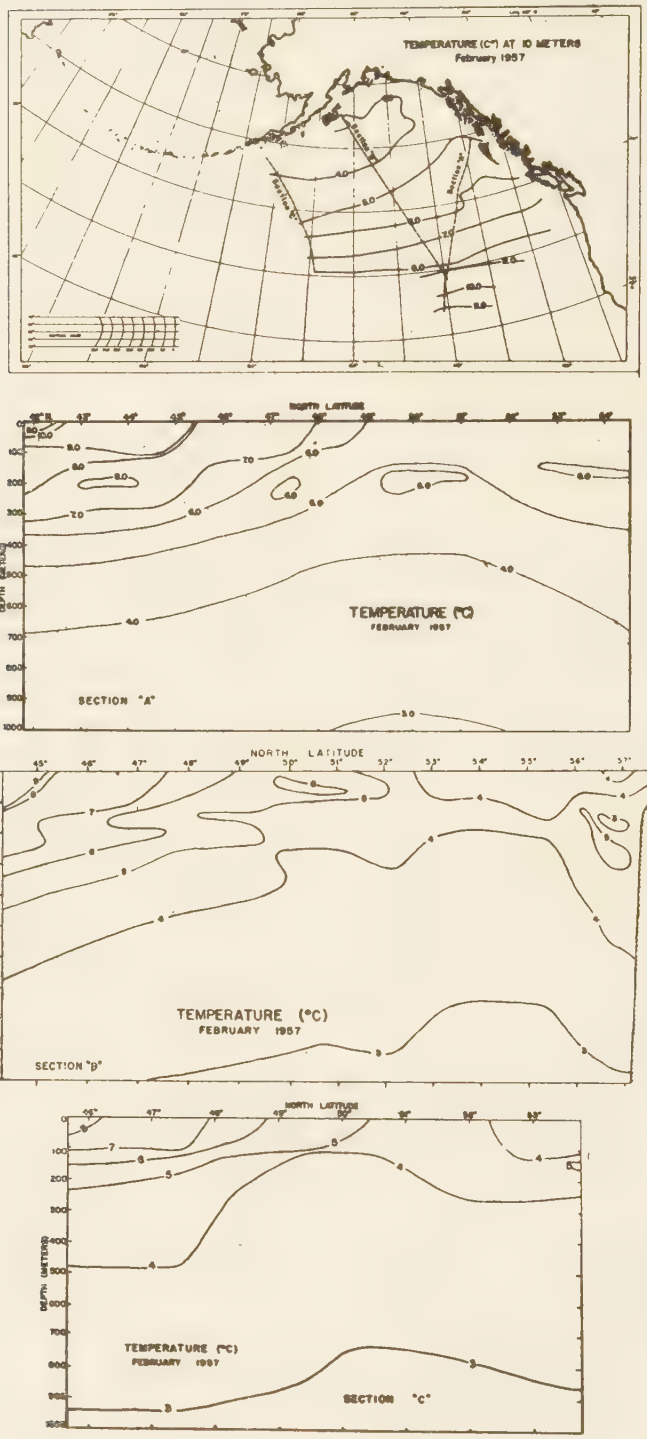

TEMPERATURE (C°) AT 10 METERS
February 1957
NORTH LATITUDE
DEPTH METERS
TEMPERATURE (°C)
FEBRUARY 1957
SECTION "A"
NORTH LATITUDE
DEPTH - METERS
TEMPERATURE (°C)
FEBRUARY 1957
SECTION "B"
NORTH LATITUDE
DEPTH METERS
TEMPERATURE (°C)
FEBRUARY 1957
SECTION "C"

Fig. 3.—

annual temperature range is nearly constant over the area. Such an examination is necessary to fully understand the phenomena.

SALINITY

The distribution of salinity over the surface, and in longitudinal section in the August survey of 1955 is shown in Fig. 6. There was a general south to north gradient over the surface. The highest salinities occurred in mid-ocean in the sub-Tropic latitudes and decreased north and east toward the North American Continent. This corresponds to the mid-ocean temperature gradient, and like it, may be regarded as a boundary between the sub-Tropic and sub-Arctic waters.

A second feature of the diagram is the plateau or secondary maximum of salinity ($32.8°/_{oo}$) in the Gulf of Alaska. Around this the salinity decreased shoreward. This salinity maximum corresponded approximately to the temperature minimum.

The longitudinal sections are most striking. Southward of latitude 36°N., the surface salinities exceeded $34°/_{oo}$ and became less with depth to a minimum between 400 and 500 meters. This is typical of the Tropic and sub-Tropic regions. North of latitude 36°N., the surface salinities were less than $33.8°/_{oo}$ at the surface and increased with depth.

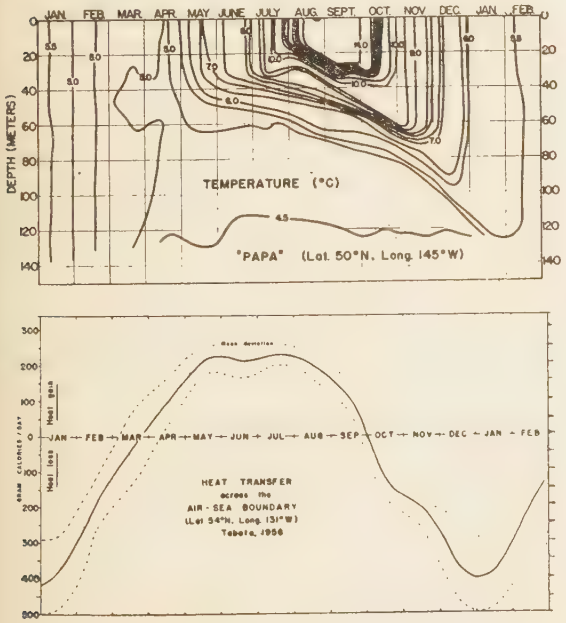

JAN FEB MAR APR MAY JUNE JULY AUG SEPT OCT NOV DEC JAN FEB
DEPTH (METERS)
TEMPERATURE (°C)
"PAPA" (Lat. 50°N, Long. 145°W)
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB
Heat gain
Heat loss
HEAT TRANSFER
across the
AIR-SEA BOUNDARY
(Lat 54°N, Long 131°W)
Tabata, 1956

Fig. 4.—

In this northern sub-Arctic region there is an upper zone of relatively homogeneous low salinity water, less than $33.0°/_{oo}$ extending to about 100 meters depth. Below this is a halocline extending to 175 to 200 meters depth in which the salinity increases to $33.8°/_{oo}$. This halocline is a boundary separating the upper low-salinity zone from the deep regions where the salinity is greater than $33.8°/_{oo}$ and increases gradually with depth. These sequences of structures along the section are illustrated in the figure.

The salinity gradients in these sections do not correspond to the temperature gradients. The south-north surface gradient marks the separation of the sub-Tropic and sub-Arctic surface waters. The vertical gradients separate the upper and lower zones. However, between latitudes 34° and 38° these are not distinguished. These are the latitudes of the so-called Polar Front as defined by the surface temperature isotherms.

Figure 7 shows similar data observed a year later, during August, 1956. The general situation was the same as in the previous year. The boundary between sub-Arctic and sub-Tropic waters was somewhat farther south, and the surface maximum in the Gulf of Alaska had a greater extent.

The winter data are shown in Fig. 8. Within the limits of normal variation, the distribution of salinity in this area was the same as in summer. That is, the salinity structure, unlike the temperature structure, is constant throughout the year.

In these figures it is notable that the halocline like the thermocline is continuous and at constant depth through the center of maximum surface salinity.

Jacobs *(2)* (Fig. 9) has shown that the low surface salinity in this area is due to the excess of precipitation over evaporation. Northward of the Polar Front there is an accumulation of fresh water in the upper zone of the ocean. The extent of this accumulation is indicated in Fig. 10. The first diagram shows a "logarithmic plot," after Tully *(6)*, of the salinity at a typical station. Examination of the Canadian part of the Norpac (August, 1955) data showed that the bottom of the halocline was defined by the isohaline $33.77°/_{oo} \pm 0.04°/_{oo}$. This was defined as the depth of the upper zone as shown in the third diagram of the figure. These data were then transferred to a natural plot (second diagram) where the dilution of the upper zone was attributed to some depth of fresh water contained in a column of unit cross-section, which had been mixed with the

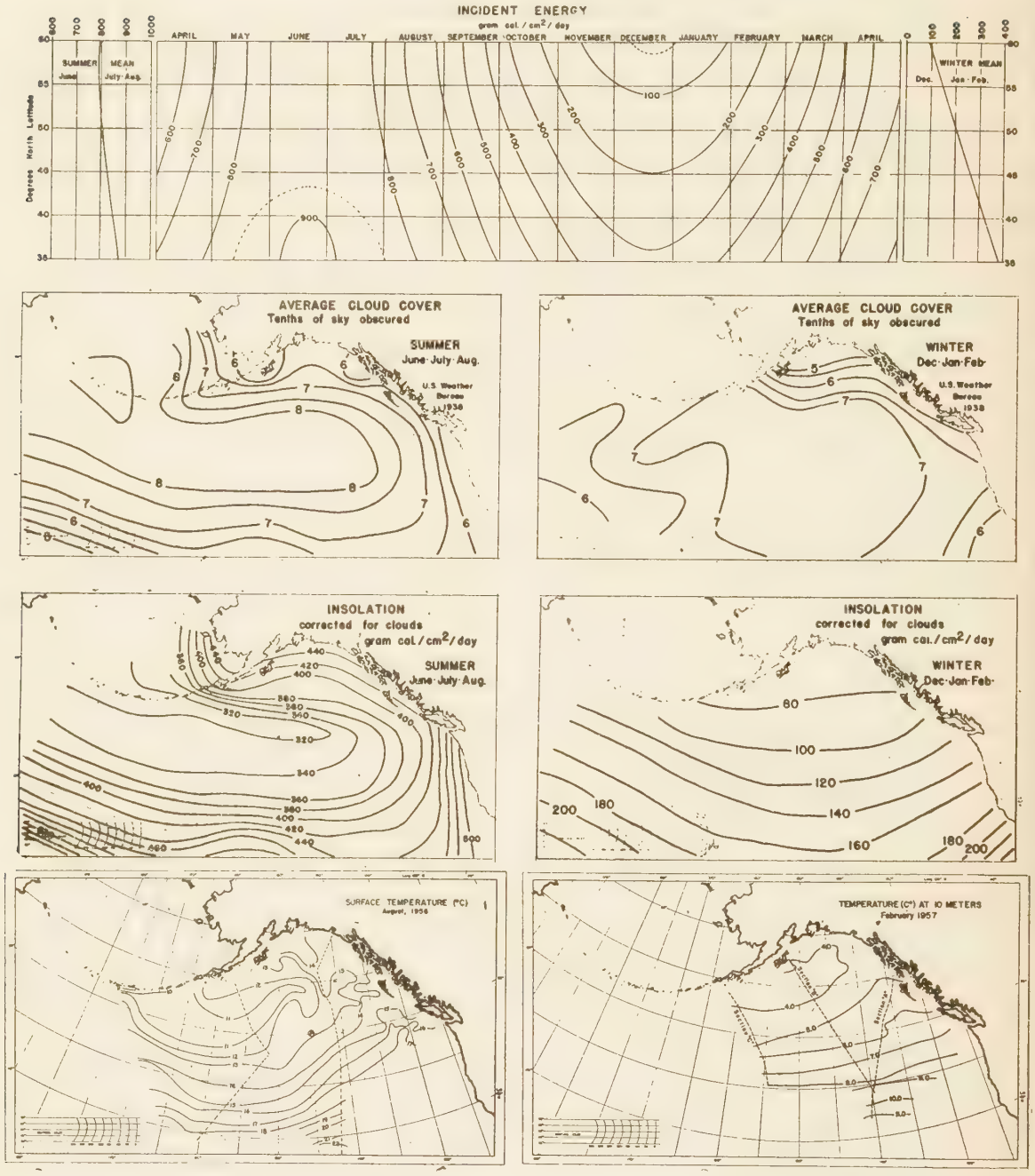

INCIDENT ENERGY
gram cal./cm²/day
APRIL MAY JUNE JULY AUGUST SEPTEMBER OCTOBER NOVEMBER DECEMBER JANUARY FEBRUARY MARCH APRIL
SUMMER MEAN
June July-Aug.
WINTER MEAN
Dec. Jan-Feb.
Degrees North Latitude
AVERAGE CLOUD COVER
Tenths of sky obscured
SUMMER
June-July-Aug.
U.S. Weather Bureau 1938
AVERAGE CLOUD COVER
Tenths of sky obscured
WINTER
Dec-Jan-Feb
U.S. Weather Bureau 1938
INSOLATION
corrected for clouds
gram cal./cm²/day
SUMMER
June-July-Aug.
INSOLATION
corrected for clouds
gram cal./cm²/day
WINTER
Dec-Jan-Feb
SURFACE TEMPERATURE (°C)
August, 1956
TEMPERATURE (C°) AT 10 METERS
February 1957

Fig. 5.—

underlying sea water of salinity 33.77°/$_{oo}$ to the depth of the upper zone.

This depth of fresh water in the upper zone of the principal part of the sub-Arctic region varies from 2.5 meters in the vicinity of salinity maximum in the Gulf of Alaska to a maximum of 5.5 meters near the coast. There is reasonable agreement between this and the previous assessment of excess precipitation considering that this is a specific picture (August, 1955) and the former (Fig. 9) is an average based on seasonal data over a long period of years.

The average accumulation of fresh water is about 3.5 meters while the average annual contribution is about 0.6 meters (60 centimeters). Hence, it may be reasoned that there is about six years accumulation of fresh water in this part of the North Pacific Ocean.

A cursory examination of the Japanese data immediately to the westward between latitudes 40° N. and 55° N. indicates that the depth of fresh water is about 2.3 meters. This difference of 1.2 meters represents about two years accumulation of fresh water in the eastern North Pacific over that present in the western area.

WATER MASSES

One convention for describing water masses is the temperature-salinity (T-S) diagram. In this the waters are identified by the relation of the two properties without reference to depth. Fig. 11 shows a sequence of representative curves, numbered for convenient reference, and the regions associated with their occurrence. The sequence of numbers was chosen to allow for extension of the study into adjacent regions. These curves represent a family of gradually changing properties throughout the northeast Pacific and are arbitrarily chosen to represent successive stages in the character of the water. Except where two or more contours come together, there are no marked boundaries, rather the properties vary from one type to the next through considerable distance.

The deep zone is similar within small limits over the whole area. However, more careful examination may show that the differences in the deep waters are significant.

The principal differences are in the upper zone. The first three curves (10, 11, and 12) denote the sub-Arctic and associated waters in which the thermocline and halocline are distinct. It has been shown that the thermocline vanishes in winter, when the upper zone structure is dependent on salinity alone. The extreme sub-Arctic water is evidently associated with the Bering Sea and the Oyashio. It is marked by minimum temperatures and a distinct temperature inversion in the halocline. In the eastern ocean the temperature of the halocline rises, the inversion is reduced or vanishes, but the salinity characteristics remain generally similar.

The other extreme is the sub-Tropic water (Type 15) in which the thermal and salinity gradients are coincident, and persist throughout the year. It is further marked by a salinity minimum which has already been discussed. This water is generally associated with the Kuroshio extension and mid-ocean circulation.

Types 13 and 14 are intermediate between the two principal water masses. Type 13 shows two thermoclines, separated by an intermediate halocline. Only the upper thermocline vanishes in winter. Type 14 represents the so-called isohaline region where the salinity is markedly irregular, and may show as many as four inversions in the upper zone.

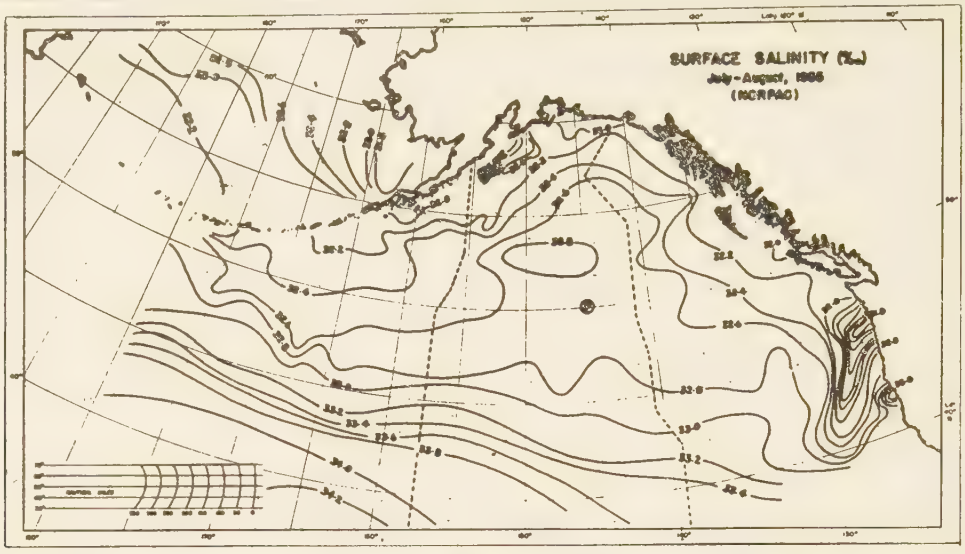
The principal boundary in the region is between the sub-Arctic and sub-Tropic waters. This boundary is most marked in mid-ocean and was more pronounced in 1955 than in 1956. Near the North American Coast the boundary region becomes broad and indistinct.

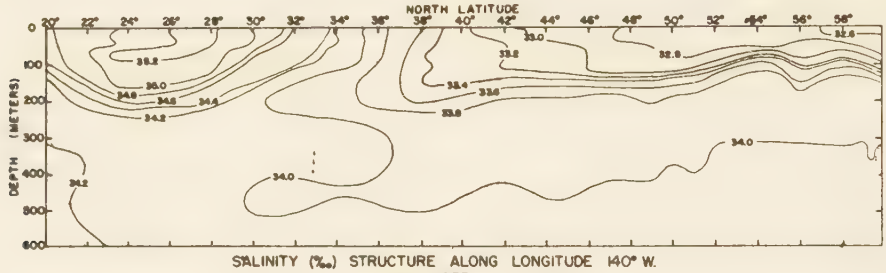
The only secondary boundary noted to date is between Types 9 and 10. The Type 9 water lying westward of longitude 180° is markedly more saline than the Type 10 water, and the transition does not fit the sequence of salinity. This is associated with a dynamic boundary.

CURRENTS

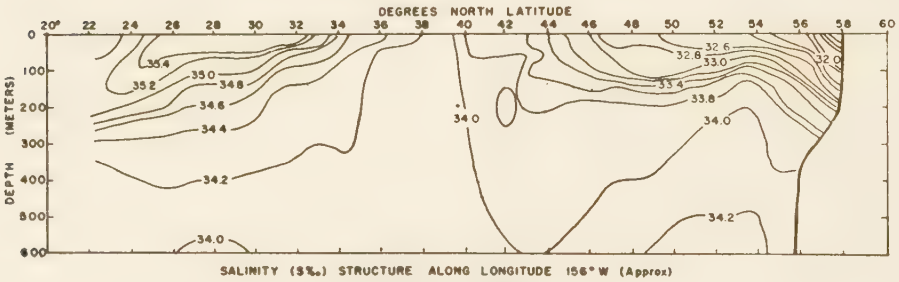
The geopotential topography in August, 1955, is shown in Fig. 12. The contours show the variations of sea surface referred to a presumed equipotential surface at 1,000 meters depth. In accord with the geostrophic principles, the current is presumed to flow along the contours with velocity proportional to the gradient across them.

The principal features of physical structure are reflected here. In the Polar Front there is a broad movement progressing eastward at less than two miles per day. The southern side of this current progresses to the American Coast where it turns southward to join the Tropical circulation system, and complete the mid-ocean circulation. The northern side of the current veers northward

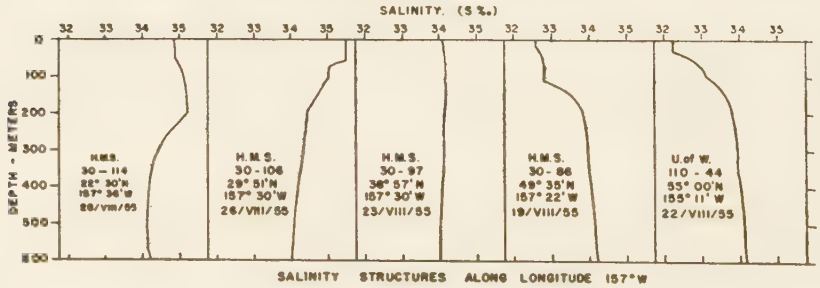




SALINITY (‰) STRUCTURE ALONG LONGITUDE 140° W.
August, 1955

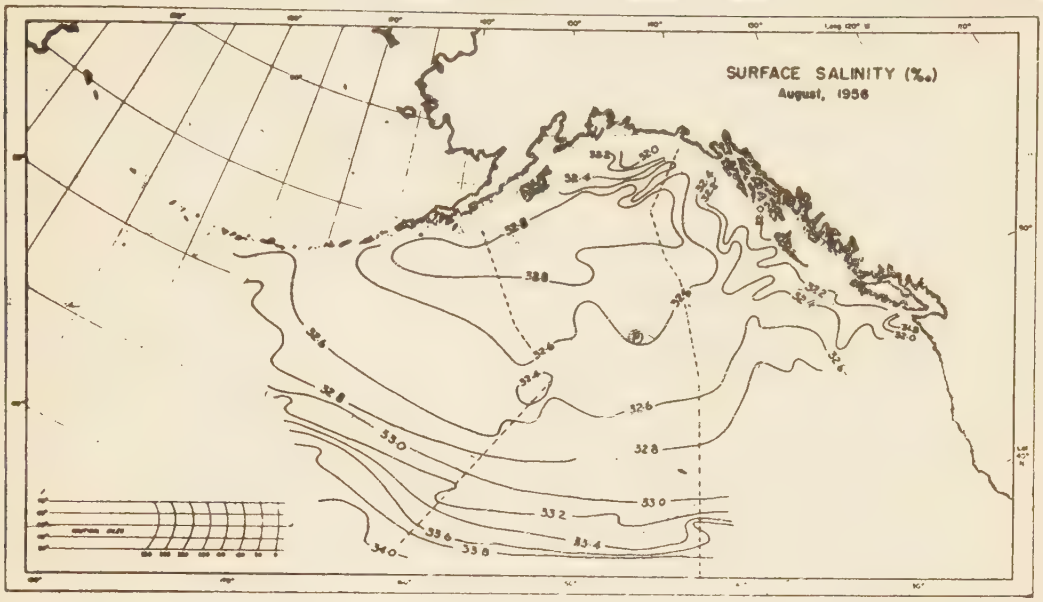


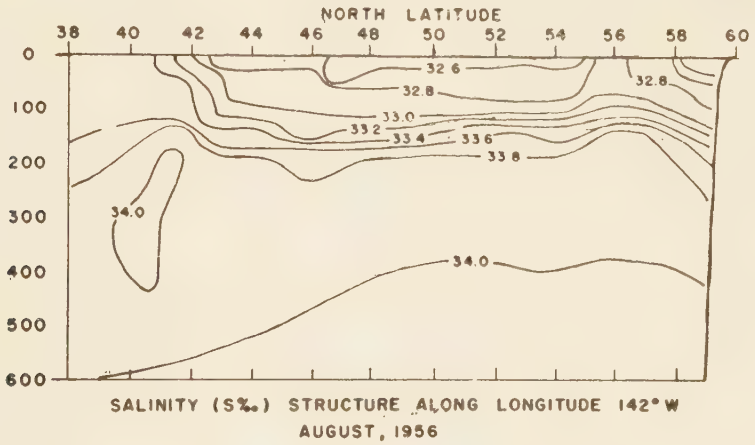
SALINITY (S‰) STRUCTURE ALONG LONGITUDE 156° W (Approx)
July - August, 1955 (NORPAC)



SALINITY STRUCTURES ALONG LONGITUDE 157°W

Fig. 6.—


SURFACE SALINITY (‰)
August, 1956
32.4
32.6
32.8
33.0
33.2
33.4
33.6
33.8
34.0


NORTH LATITUDE
38 40 42 44 46 48 50 52 54 56 58 60
0
100
200
300
400
500
600
32.6
32.8
33.0
33.2
33.4
33.6
33.8
34.0
34.0
SALINITY (S‰) STRUCTURE ALONG LONGITUDE 142° W
AUGUST, 1956

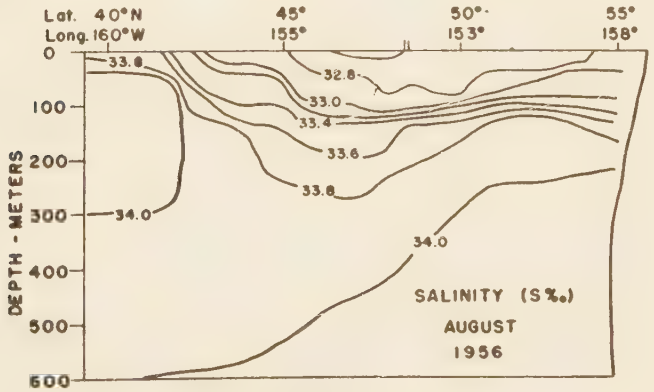

Lat. 40°N 45° 50° 55°
Long. 160°W 155° 153° 158°
0
100
200
300
400
500
600
DEPTH - METERS
33.8
32.8
33.0
33.4
33.6
33.8
34.0
34.0
SALINITY (S‰)
AUGUST
1956

Fig. 7.—

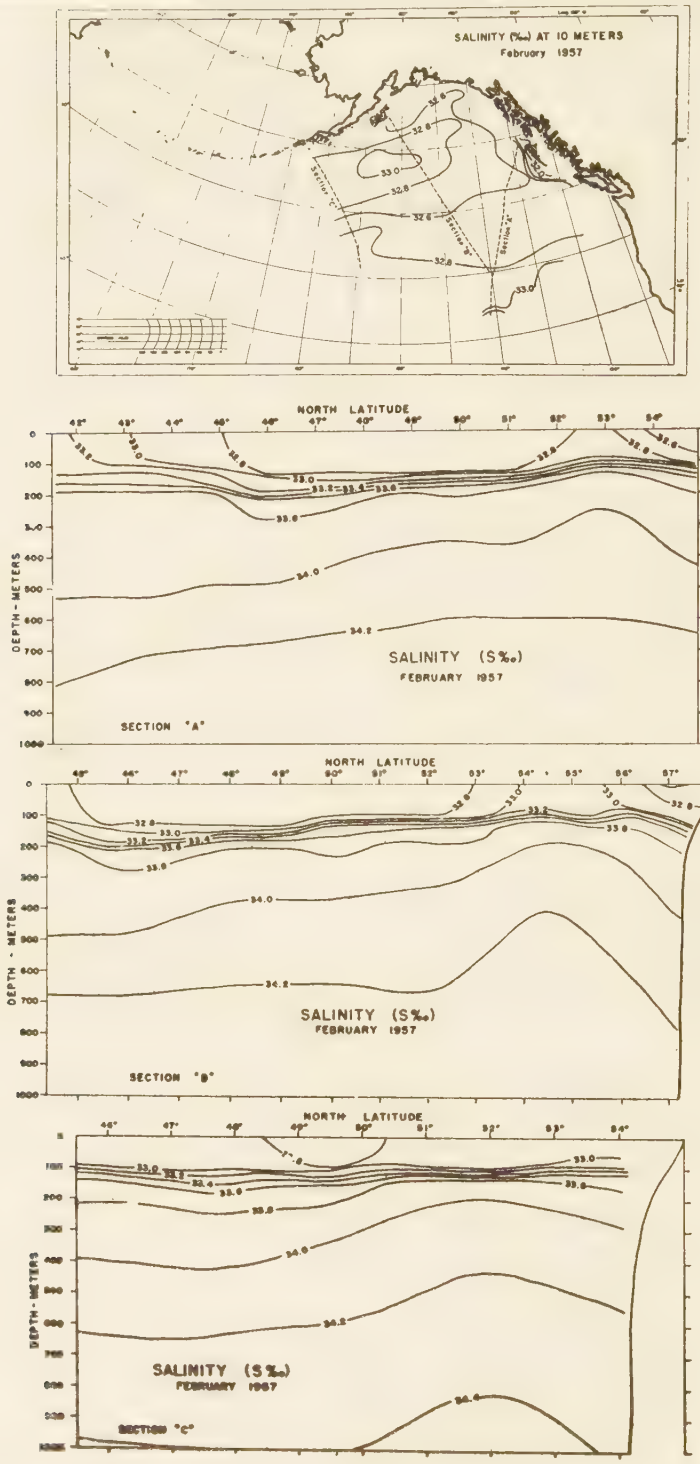

SALINITY (‰) AT 10 METERS
February 1957
NORTH LATITUDE
DEPTH - METERS
SALINITY (S‰)
FEBRUARY 1957
SECTION "A"
SECTION "B"
SECTION "C"

Fig. 8.—

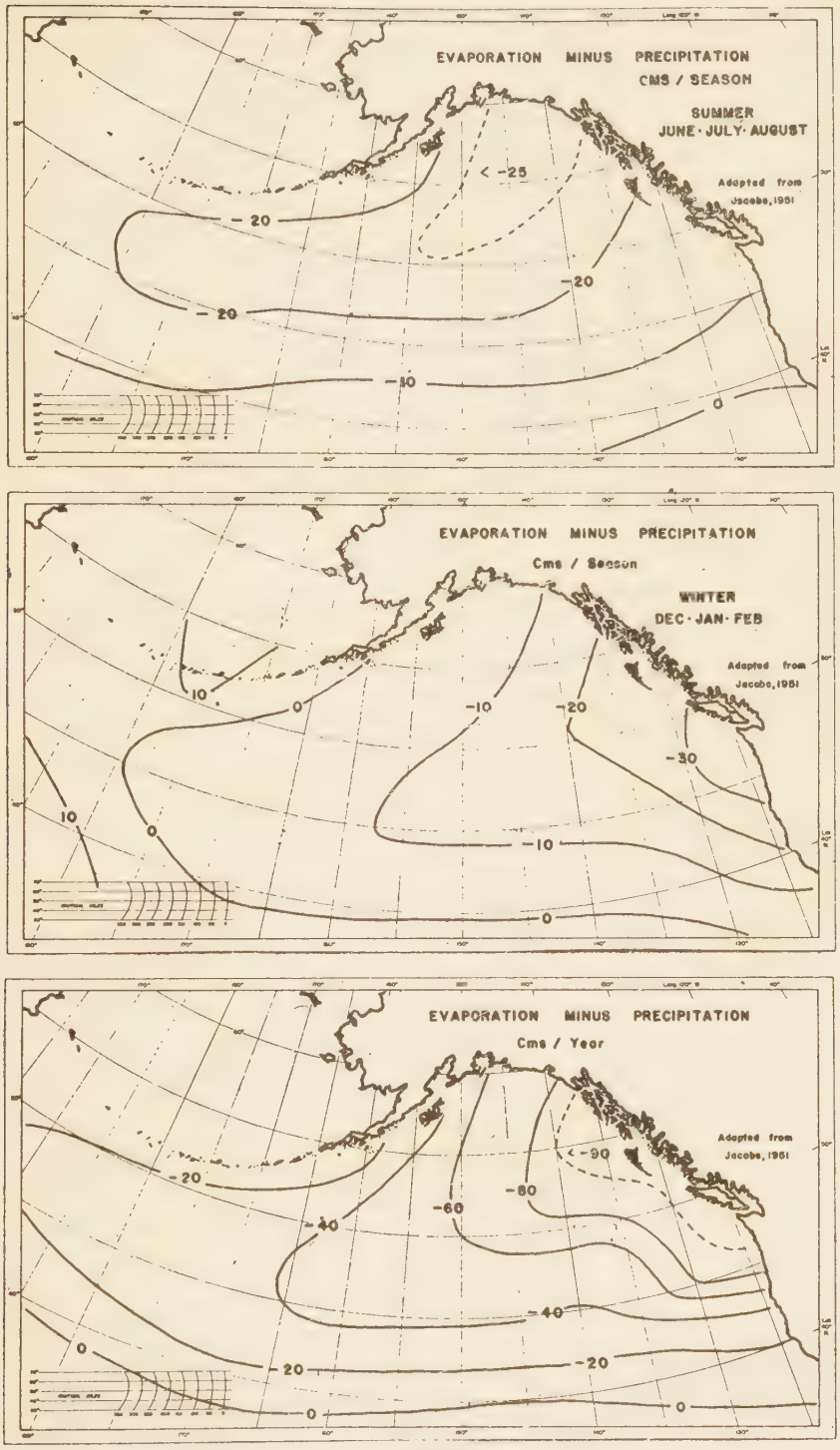

EVAPORATION MINUS PRECIPITATION
CMS / SEASON
SUMMER
JUNE · JULY · AUGUST
Adapted from Jacobs, 1951
< -25
-20
-20
-20
-10
0
EVAPORATION MINUS PRECIPITATION
Cms / Season
WINTER
DEC · JAN · FEB
Adapted from Jacobs, 1951
10
0
-10
-20
-30
10
0
-10
0
EVAPORATION MINUS PRECIPITATION
Cms / Year
Adapted from Jacobs, 1951
< -90
-80
-60
-40
-20
-40
0
-20
-20
0
0

Fig. 9.—

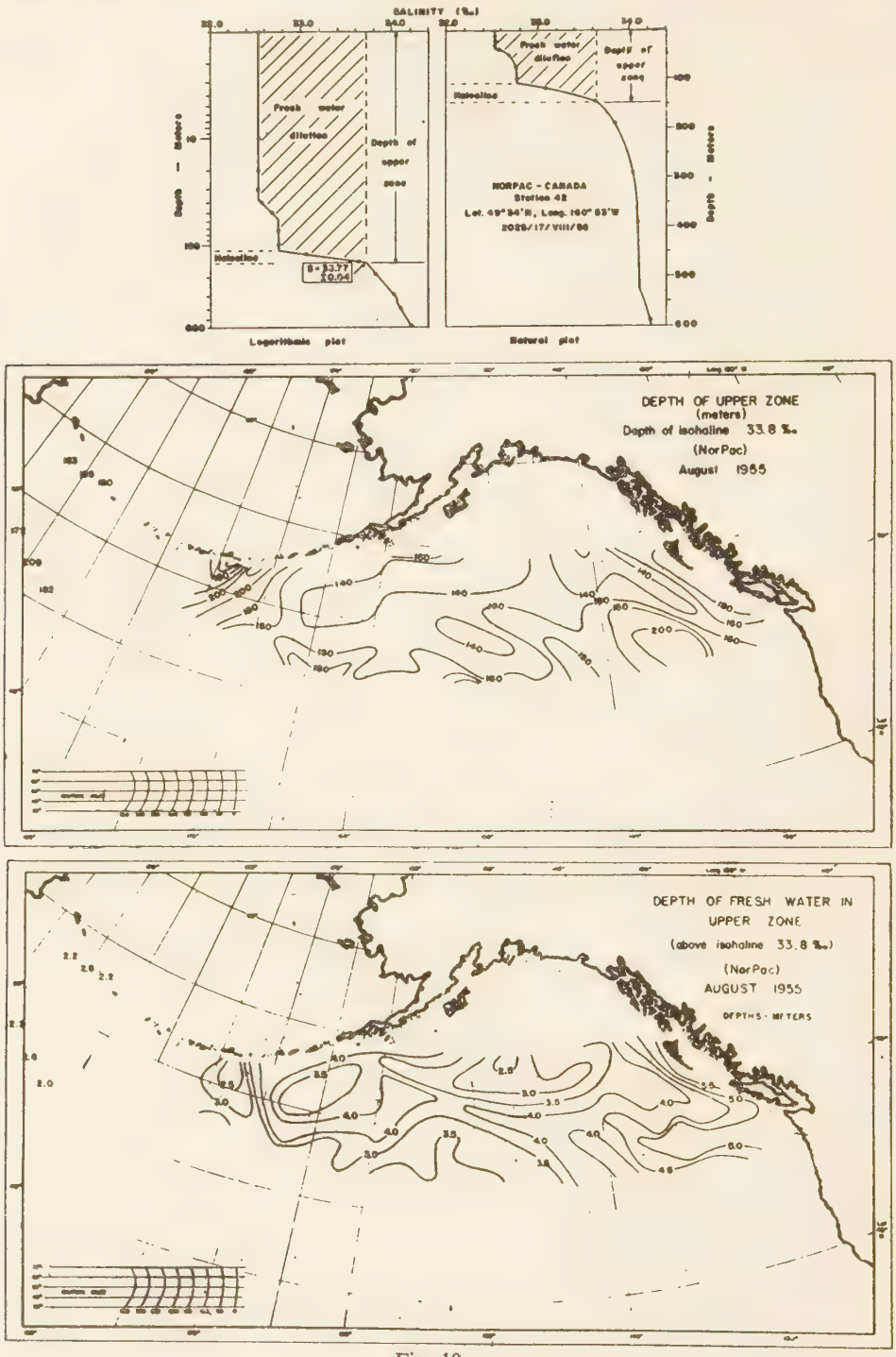

SALINITY (‰)
Fresh water dilution
Depth of upper zone
Halocline
NORPAC - CANADA
Station 42
Lat. 49° 34' N, Long. 160° 03' W
2025/17/VIII/55
Logarithmic plot
Natural plot
DEPTH OF UPPER ZONE
(meters)
Depth of isohaline 33.8 ‰
(NorPac)
August 1955
DEPTH OF FRESH WATER IN
UPPER ZONE
(above isohaline 33.8 ‰)
(NorPac)
AUGUST 1955
DEPTHS - METERS

Fig. 10.—

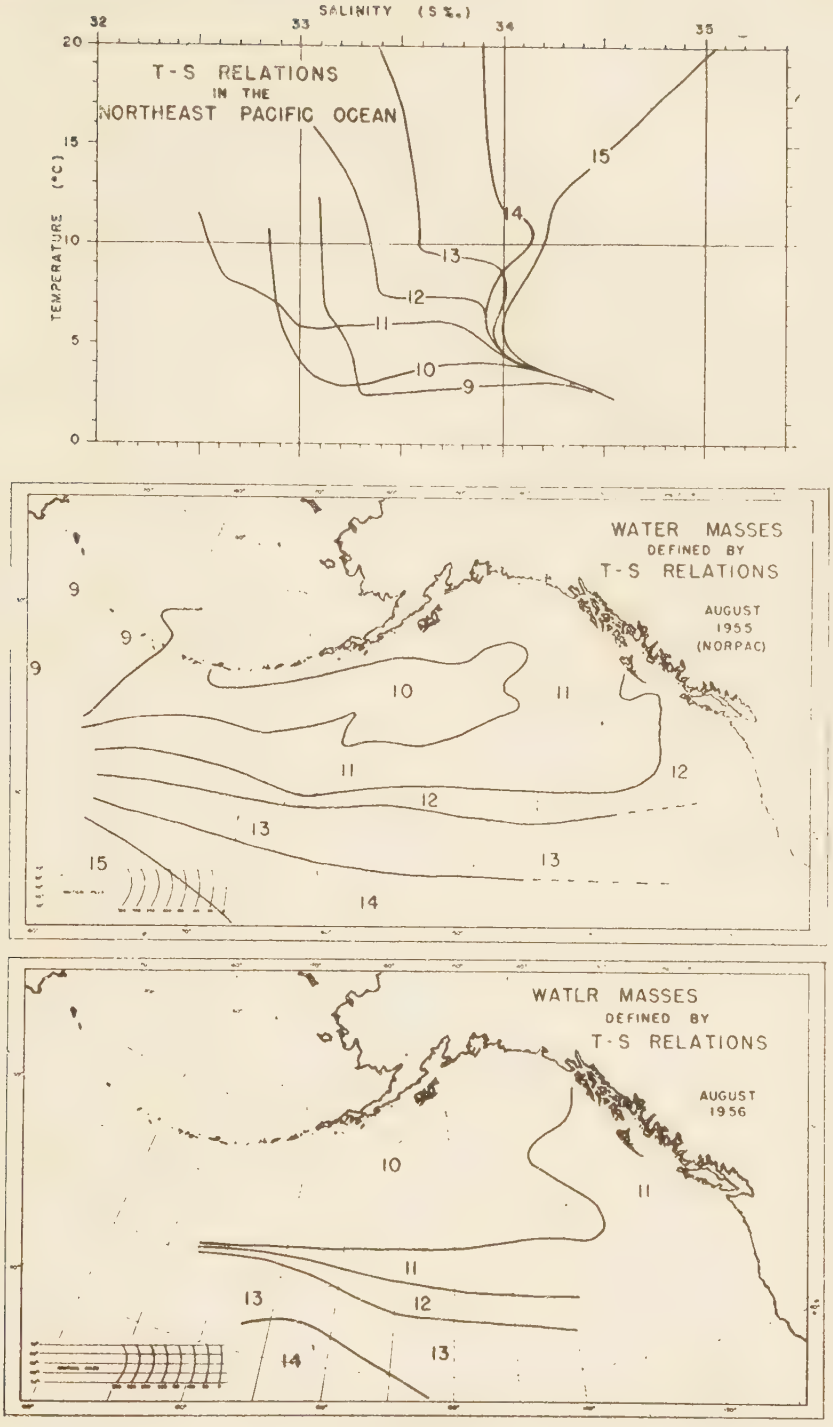

SALINITY (S‰)
32
33
34
35
20
15
10
5
0
TEMPERATURE (°C)
T-S RELATIONS
IN THE
NORTHEAST PACIFIC OCEAN
15
14
13
12
11
10
9
WATER MASSES
DEFINED BY
T-S RELATIONS
AUGUST
1955
(NORPAC)
9
9
9
10
11
11
12
12
13
13
15
14
WATLR MASSES
DEFINED BY
T-S RELATIONS
AUGUST
1956
10
11
11
13
12
14
13

Fig. 11.—

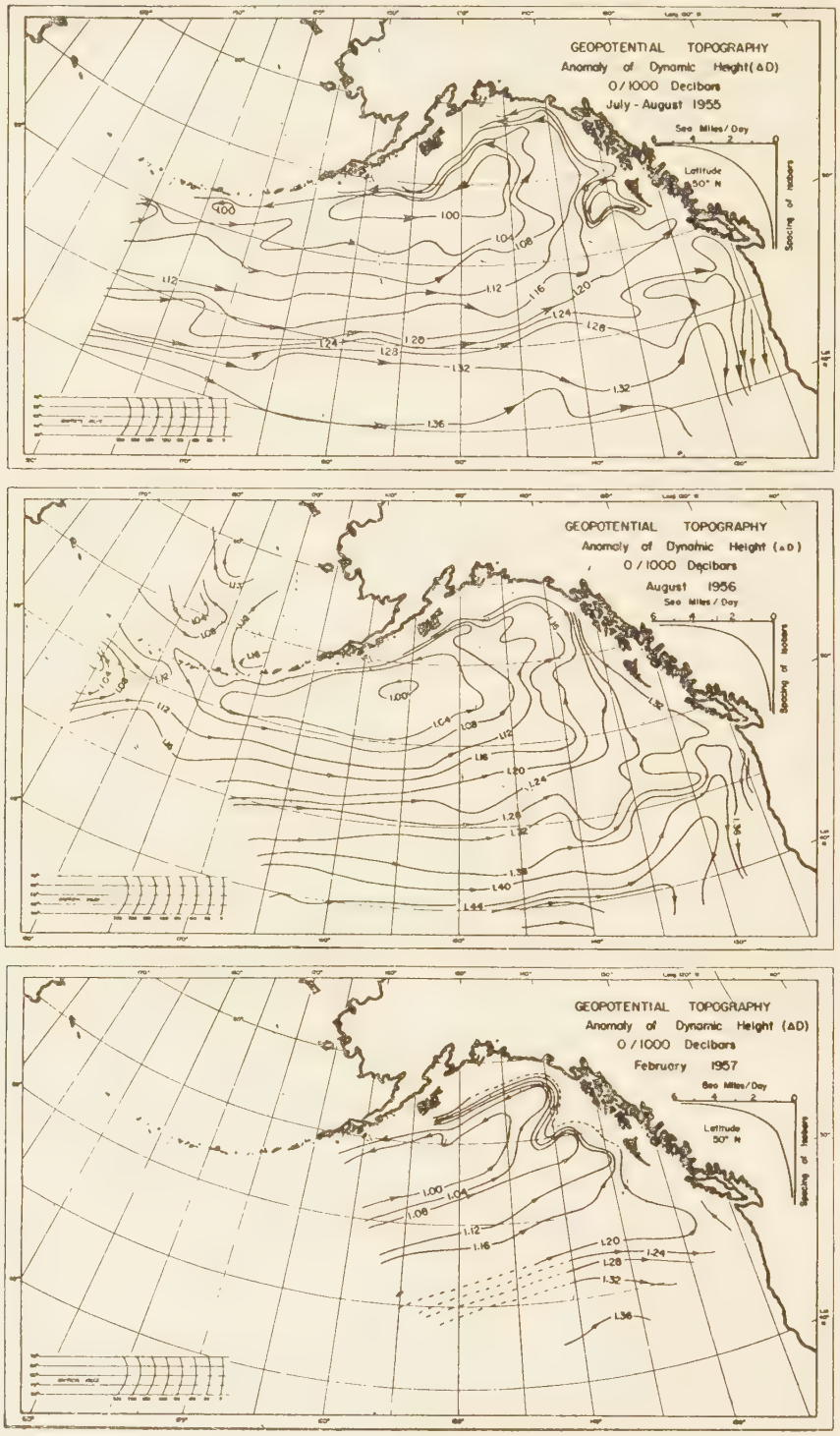

GEOPOTENTIAL TOPOGRAPHY
Anomaly of Dynamic Height (ΔD)
0 / 1000 Decibars
July - August 1955
Sea Miles / Day
Latitude 50° N
Spacing of Isobars
GEOPOTENTIAL TOPOGRAPHY
Anomaly of Dynamic Height (ΔD)
0 / 1000 Decibars
August 1956
Sea Miles / Day
Spacing of Isobars
GEOPOTENTIAL TOPOGRAPHY
Anomaly of Dynamic Height (ΔD)
0 / 1000 Decibars
February 1957
Sea Miles / Day
Latitude 50° N
Spacing of Isobars

Fig. 12. —

around the Gulf of Alaska and is strongly intensified along the Alaska Peninsula. The contours indicate that very little of this water is recirculated; therefore, it is deduced that the current moves eastward close along the Aleutian Islands and is dissipated through the passages into the Bering Sea. There is some evidence in the figure of a strong northward set in the vicinity of longitude 180° and a cyclonic gyral in the western Bering Sea. Earlier studies in 1947*(4)* showed a northward and westward movement in the eastern Bering which accords well with these observations.

The diagram suggests that the sub-Arctic waters form a closed circulation. The Oyashio waters move south along the Asiatic Coast to meet the Kuroshio waters advancing from the south. The two waters turn eastward mingling, and cross the ocean in a broad movement in which there is a south-north gradient of properties. The northern side of this current, consisting chiefly of Oyashio water, circulates around the Gulf of Alaska and is largely dissipated into the Bering Sea where it rejoins the Oyashio.

Later summer data confirms the principal features of this circulation pattern. It was originally imagined that the system might be accelerated in winter and continue by virtue of momentum through the summer. However, the winter data show that the circulation is not significantly different in this season.

REFERENCES

(1) Hollister, H.J., 1956, The program of bathythermograph observations at the Canadian ocean weather station PAPA (50°00′ N., 145°00′ W.). Fisheries Research Board of Canada, Joint Committee on Oceanography, *MS Report*, 17 pp.

(2) Jacobs, Woodrow C., 1951, The Energy Exchange between Sea and Atmosphere and Some of Its Consequences. *Bull. Scripps Institution of Oceanography*, **6** (2).

(3) Robinson, Margaret K., 1956, Sea temperatures in the Gulf of Alaska and in the Northeast Pacific Ocean, 1941-1952. *MS* submitted to *Bulletin of the Scripps Institution of Oceanography*.

(4) Saur, J.F.T. Jr., Lesser, R.M., Carsola, A.J., and Cameron, W.M., 1952, Oceanographic cruise to the Bering and Chukchi Seas, Summer, 1949. *U.S. Navy Electronics Laboratory Report*, No. 298.

(5) Tabata, S., 1957, Heat exchange between sea and atmosphere along the northern British Columbia coast. *Fish. Res. Bd. Canada, Prog. Rept. Pac.*, **108**.

(6) Tully, J.P., 1953, Some characteristics of seawater structure. Fisheries Research Board of Canada, Joint Committee on Oceanography, *MS Report*, 21 pp.

(7) ——— and Dodimead, A.J., 1957, Canadian oceanographic research in the north Pacific Ocean. Fisheries Research Board of Canada, Joint Committee on Oceanography, *MS Report*, 11 pp.

(8) U.S. Department of Agriculture, Weather Bureau, 1938, *Atlas of Climatic Charts of the Ocean*. W.B. No. 1247. Washington, D.C.

DISCUSSION

K. HIDAKA: Salinity minima at the surface are hard to explain when we seek the origin of deep waters.

F. NEAVE: Low surface salinity is widespread until you get down below latitude 36° N.

CURRENTS AND WATER STRUCTURE IN QUEEN CHARLOTTE SOUND, BRITISH COLUMBIA

F.G. BARBER

Pacific Oceanographic Group, Nanaimo, B.C., Canada.

Data are available from recent oceanographic surveys of the oceanic and coastal waters of the northeast Pacific, and particularly of these waters in the Gulf of Alaska. One feature of the area is an excess of precipitation over evaporation. This excess, together with an accumulation of the fresh water in the surface layers, is evidenced in the salinity structure which is observed over the entire gulf region. At the surface, salinities are everywhere less than 33.0°/$_{oo}$ generally decreasing toward the coasts.

There is an upper zone of relatively homogeneous low salinity water, less than 33.0°/$_{oo}$ extending to about 100 meters depth. Below this, and to a depth of about 170 meters, is a well-defined halocline in which the salinity increases to 33.8°/$_{oo}$. This halocline is a boundary separating the upper zone from a deep zone where the salinity is greater than 33.8°/$_{oo}$ and increases with depth.

This structure is observed during all seasons.

The excess of precipitation is greatest near

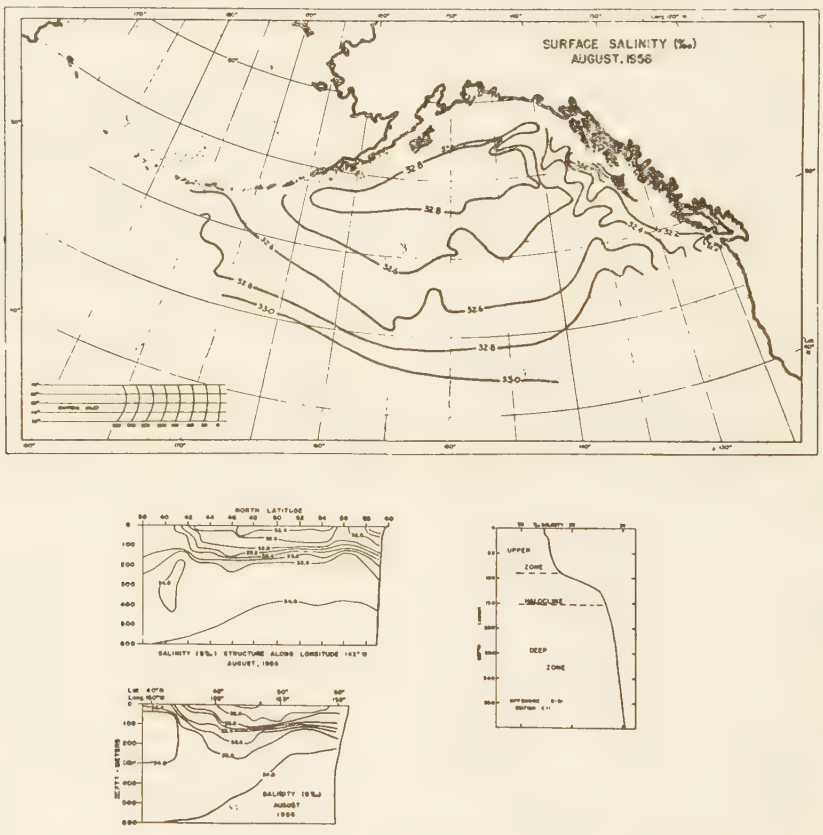


Fig. 1.—Surface salinity, salinity in longitudinal section and structure in the Gulf of Alaska region.

the coasts where, in addition, large volumes of fresh water from land drainage enter the sea. The seaward entry of this land drainage very often occurs only after passage through extensive coastal seaways in which conditions of extreme tidal turbulence occur. By the time the sea is reached, the outflowing water has attained a salinity very near that of surface zone water in the ocean.

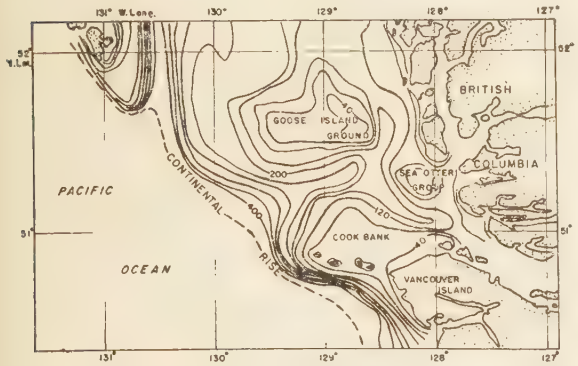


Fig. 2.—Chart of Queen Charlotte Sound.

A characteristic of the coast along the eastern periphery of the Gulf of Alaska is that there are many such seaways; a representative example is that of Queen Charlotte Sound. The principal features of the sound are shown in Fig.2. The Pacific Ocean and the continental rise lie to the west, the mainland of British Columbia to the east. Extensive shallow areas and deep trenches extending from seaward are marked features. One of the principal trenches is that which lies between Cook Bank and the Goose Island Ground and extends into the seaway between Vancouver Island and the mainland. As can be seen, there are numerous coastal indentations and seaways close to this principal channel.

The distribution of surface salinity during the summer (June, 1955) is indicated in Fig.3. The fact that the greatest volume of fresh water reaches the sound in the vicinity of the principal channel is indicated by the tongue of relatively low salinity water extending seaward from this region.

The summer distribution of salinity in a vertical section through the principal channel is shown in Fig.3. Between the surface and 50 meters depth, relatively low salinity water less than 32.5°/$_{oo}$ dominated. The effect of the freshwater outflow from adjacent channels is reflected in the lower salinity values observed at the surface in mid-section. Below about 50 meters depth, the salinity is everywhere greater than 32.8°/$_{oo}$ and increases with depth to at least 33. 6°/$_{oo}$. As we saw, these are the same salinities as observed in the oceanic halocline. It is evident that oceanic waters have intruded well into the inner reach of the seaway, as there is no other source of water in the coastal region.

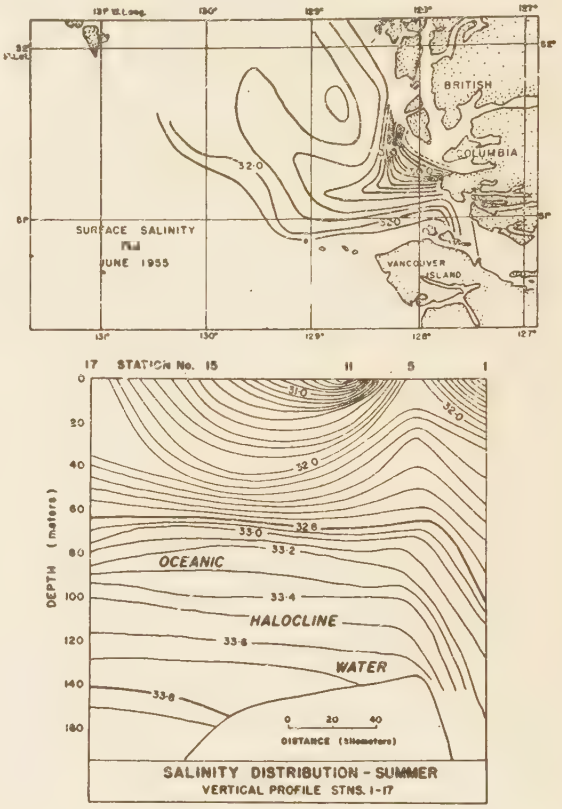


Fig. 3.—(a) Surface salinity summer.
(b) Salinity in a section through the principal channel.

It is interesting to note that the range of salinities and the structure at seaward end of this section are very nearly the same as those observed farther seaward in the Gulf of Alaska. It is evident that the oceanic structure is attained within the coastal regions.

At positions in the vicinity of the principal channel, hourly Ekman current observations

were made for periods up to 50 hours. The data were analysed to obtain the net movement at each depth at each position.

These net movements as calculated for two of the more seaward stations indicated a persistent movement of the deep and bottom water into the sound and toward the inner reach of the principal channel.

The salinity identifies the deep water as coming from the region of the oceanic halocline. The current data show that it is persistently intruding the coastal seaway being entrained and dissipated in the near surface waters. The shoreward movement of deep waters is consequent on the upward transport of this water into the surface seaward-moving layers.

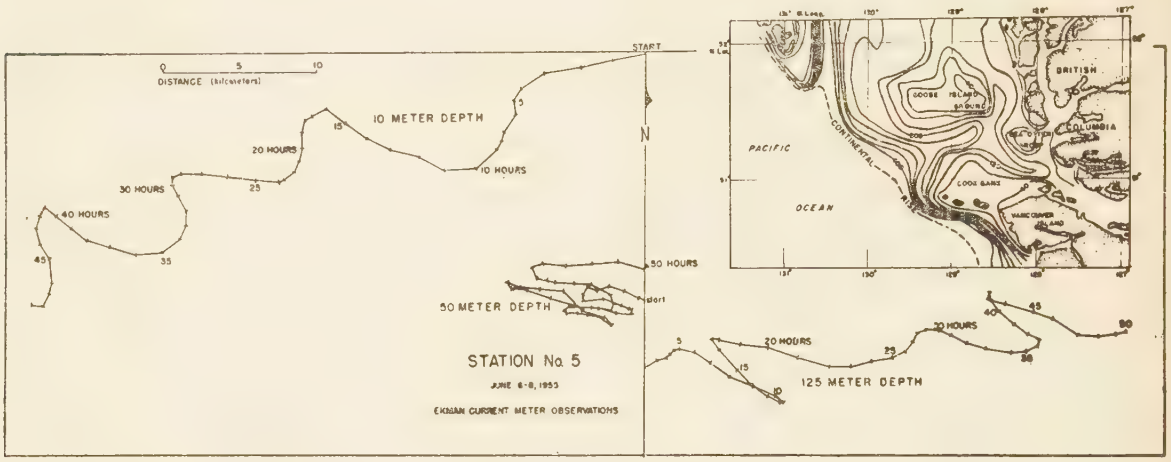


Fig. 4.—Current observations at 10, 50, and 125 meter depths at Station 5.

Data obtained in the shoreward end of the channel during a 50-hour period are indicated in Fig. 4. At the 10-meter depth a seaward movement occurred which, during a tidal day was about 20 kilometers. At the 50-meter depth it can be seen that little net movement occurred. At the 125-meter depth (the deepest depth of observation at this position), a large net movement again occurred; it was, however, directed shoreward and about 15 kilometers per day.

The vertical distribution of net movement at this position is summarized in Fig. 5. Above 50 meters, a net seaward movement occurred with a maximum rate of over 20 cm/sec at the surface, decreasing steadily to nearly zero at 50 meters. Below 50 meters, a movement into the seaway occurred which, between 75 and 125 meters, averaged about 15 cm/sec.

In the deep water, therefore, the inflow is continuous from seaward well into the inner reach of the principal channel. The contrary directions of the surface and deep water indicate the existence of considerable shear with consequent mixing occurring at all depths.

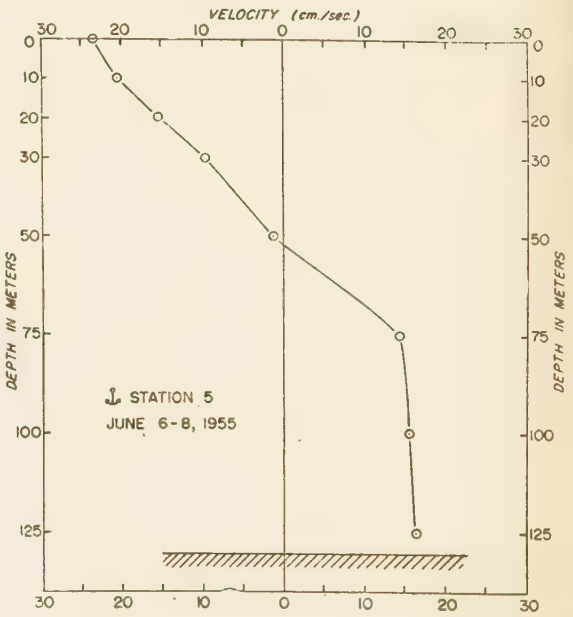


Fig. 5.—Vertical profile of net movement at Station 5.

It is known that the maximum land drainage into this region occurs during the summer, a minimum in early spring; and while no quantitative assessment has been made of the seasonal nature of the discharge through the seaway, it is considered that sufficient surface outflow occurs to allow the entrainment process, and hence the deep inflow, to persist during all seasons. This leads to a consideration of the source water comprising the deep inflow.

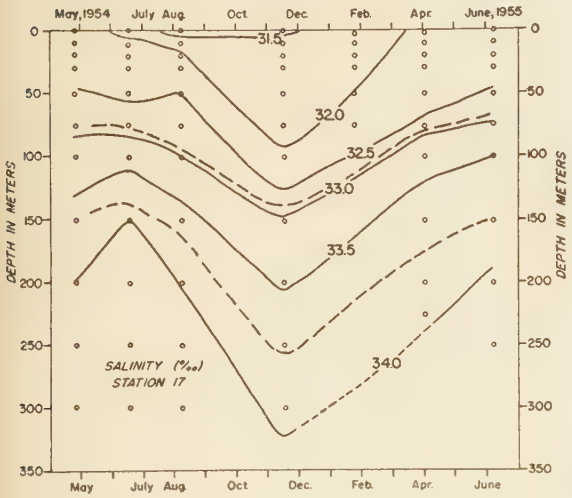


Fig. 6.—Seasonal variation of the depth of the halocline.

During the prevalence of southerly winds along the coast, usually strongest from autumn through the winter to early spring, the oceanic halocline is depressed below the level of the continental shelf. The alternate condition is associated with light or northwest winds, and maximum run-off when the oceanic halocline rises along the coast. These conditions occur most frequently during the summer.

This depth variation of the halocline leads to marked changes in the salinity of the deep inflow which is in turn reflected in changes of the salinity of the water in the entire system. In December, 1954, after a prolonged period of southerly winds, the salinity of sound water was about $1^{\circ}/_{\circ\circ}$ less at all depths than during the summer.

These variations in the salinity of source water then of deep inflow have a profound effect on the characteristics of coastal water. This is further emphasized by the fact that the period at which the salinity of sound water is a maximum occurred at a time of maximum run-off. Evidently the character of the water is dominated more by the deep inflow than by the amount of run-off. The same conclusion regarding the effect of the deep inflow has been expressed by Waldichuk in a study of the Strait of Georgia system—some 200 miles farther south.

Finally, in these seaways fresh and ocean waters are mixed to ocean structure within the limits of the coastal seaway. The deep inflow provides a mechanism through which oceanic conditions are reflected in inshore waters such as these. A consideration of all the data suggests that complete renewal of the deep and bottom water could occur in a period as short as two weeks. This may be of considerable significance in this important fishing area.

IODINE DISTRIBUTION IN THE WESTERN PACIFIC OCEAN†

KEN SUGAWARA and KIKUO TERADA

Chemical Institute, Faculty of Science, Nagoya University, Nagoya, Japan.

(Abstract)

1. By using the method of determining minute quantities of iodide which was established by the present authors, the distribution of various forms of iodine in the Western Pacific Ocean was determined.

2. In number, 326 samples were collected from different levels at 50 stations distributed in an area extending from the northern end of the Bering Sea to the Equator and from the north-eastern part of the Japanese Main Island to a point close to Hawaii.

3. The data of analysis revealed: a) that the iodine in sea water is practically all in two different forms, iodide and iodate; b) that total iodine averages 0.304 g/l and the percentage of iodide to total iodine varies from 0 to 100%; c) that for the surface water, total iodine tends to decrease from the north towards the Equator, the off-shore waters of Japan's Main Island being remarkably high in their total iodine value; d) that for iodide, iodate and total iodine, there is no regular vertical variation, the exception being that the amount of total iodine is generally small at the surface layers in comparison with the value at subsurface layers.

4. As factors possibly contributing to the variation of iodine in sea water, the following were mentioned: a) Removal of iodine through assimilation by planktonic organisms and addition of the element liberated from decay of organic materials into the water; b) Selective capturing of iodine by flocculent hydroxides of metals sinking to the bottom; c) Addition of iodine by outflow of land waters in which the ratio I/Cl is greater than in sea water; d) Selective escape of iodine from the sea surface.

5. Kinds of factors which possibly cause the variation in iodide-iodate ratio were mentioned.

† Published in *The Journal of Earth Sciences*, Nagoya University, Japan, Vol. 5, No. 2, 1957.

ON THE CALCULATION OF DAILY VARIATIONS OF SEA TEMPERATURE

A. G. KOLESNIKOV

Marine Hydrophysical Institute, Academy of Sciences of the USSR, Moscow, USSR.

(Abstract)

My paper deals with an oceanographical problem which is of considerable importance to the oceans and seas of mean latitudes. I refer to the daily variations of surface temperature.

In our former research (*1*, *2*), a method of calculating the curve of daily variations of sea temperature which are characteristic of different sea depths was used. Thus we obtained data dealing with daily variations of all the components of heat exchange, i.e., solar radiation, effective back radiation, turbulent exchange and heat exchange by evaporation. As is shown by our comparisons, the method proved that the curves which were observed and the calculated curves coincide.

But in order to decrease the number of elements needed for the calculation, one can change the form of the task, without diminishing the community, in such a way that it will be sufficient for the calculation of daily sea measurements to know initially the daily changes of air temperature at a definite height, the incoming solar radiation taking into consideration the albedo of sea surface, and characteristics of the turbulent exchange of sea and air. In this report I propose to use the following calculation, the basic theoretical principals of which are formulated (*3*).

Let us accept as given that the spreading of heat both in the sea and in the atmosphere above the sea is going on only in a vertical direction. It is worth mentioning that transfer of heat to the sea is carried out by a turbulent exchange and a radial energy stream (but in atmosphere only by turbulent exchange).

We shall calculate the daily variation only with application to those periods when the zone of density's change in the sea is located below the zone where daily variations of temperature are spreading. That is why in the upper completely mixed zone we can accept the coefficient of turbulent heat exchange as a constant one.

Under these conditions temperature distribution in the sea and sub-surface zone of the atmosphere are described by equations (1) and (2). We must keep in mind not the temperature itself but its variations from a mean daily datum.

$$\frac{\partial t_1}{\partial \tau} = K_1 \frac{\partial^2 t_1}{\partial z^2} + \sum_{m=1}^{\nu} \frac{1 - A_m}{c_1 \rho_1} \beta_m I_m(\tau) e^{-\beta m z} \quad \ldots (1)$$

$$\frac{\partial t_2}{\partial \tau} = K_2 \frac{\partial}{\partial z}\left\{(1 + \mu z) \frac{\partial t_2}{\partial z}\right\} \quad \ldots (2)$$

Here are used the following abbreviations:

z — vertical coordinate,
τ — time,
A_m and β_m — albedo and coefficient of absorption for the m^{th} part of the spectrum,
$I_m(\tau)$ — stream of radial energy relating to the m^{th} part of the spectrum,
K_1 and K_2 — coefficients of a turbulent heat conduction of sea and atmosphere, $K_2 = \kappa V_* z_0$, $\kappa = 0{,}4$,
$\mu = \frac{1}{z_0}$ — characteristic of the increase of the latter with the height.

As limiting conditions we are taking the following factors: equality of temperatures and a full balance of heat on the surface:

$$t_1(0,\tau) = t_2(0,\tau) \quad \ldots (3)$$

$$\left.\begin{aligned} c_1\rho_1 K_1 \frac{\partial t_1}{\partial z}\Big|_{z=0} - c_2\rho_2 K_2 (2) \frac{\partial t_2}{\partial z}\Big|_{z=0} = \\ = \phi(\tau) - 4 a \sigma T_0^3 t_1(0,\tau) \end{aligned}\right\} \quad \ldots (4)$$

where we have used the following abbreviations:

$\phi(\tau) = aG(\tau) - q_u(\tau)$,
c — heat capacity,
ρ — density,
$a\sigma$ — radiative capacity of the sea surface,
$G(\tau)$ — opposing (meeting) radiation of atmosphere,
$q_u(\tau)$ — heat exchange as a result of evaporation or condensation.

Let us look for a periodic decision relating to the given task, considering daily variations of temperature as fixed.

Let us approximate the daily variations of solar radiation which were already known.

$$I_m(\tau) = \sum_{n=1}^{j} \left\{ A^I_{m,n} \cos n\omega\tau + B^I_{m,n} \sin n\omega\tau \right\} \ldots (5)$$

We do the same with the variations of the temperature at the height h above the sea surface. The sum is as follows:

$$t_2(h,\tau) = \sum_{n=1}^{j} \left\{ A^t_n \cos n\omega\tau + B^t_n \sin n\omega\tau \right\} \ldots . (6)$$

Now let us imagine an unknown function $\phi(\tau)$

$$\phi(\tau) = \sum_{n=1}^{j} \left\{ A^{\varphi}_n \cos n\omega\tau + B^{\varphi}_n \sin n\omega\tau \right\} \ldots \ldots . (7)$$

We have found that the distribution of temperature in the sea and in the atmosphere in a form:

$$\left.\begin{aligned} t_1(z,\tau) &= \sum_{m=1}^{v} U_m(\tau)\, e^{-\beta_m z} + \\ &+ \sum_{n=1}^{j} Re \left\{ C_{1n}\, e^{-(1-i)\sqrt{\frac{n\omega}{2K_2}} z - in\omega\tau} \right\} \end{aligned}\right\} \ldots \ldots (8)$$

$$\left.\begin{aligned} t_2(z,\tau) = \sum_{n=1}^{j} Re \Bigg\{ C_{2n}\, H_0^{(1)} \Bigg[\\ \left[\frac{2}{\mu} \sqrt{i \frac{n\omega}{K_2} (1+\mu z)} \right] e^{-in\omega\tau} \Bigg\} \end{aligned}\right\} \ldots \ldots (9)$$

where $\omega = \frac{2\pi}{T}$, T — one day time-period

$H_0^{(1)}(x)$ — Hankel function of zero order

In this case *Re* signifies a real part of an existing part.

I shall drop further details and will demonstrate the final form of the expression which shows the distribution of sea temperature variations at any given moment, at any depth in the zone of daily variations:

$$\left.\begin{aligned} t_1(z,\tau) = \sum_{n=1}^{j} N_n e^{-\sqrt{\frac{n\omega}{2K_2}} z} \cos\Big(n\omega\tau - \sqrt{\frac{n\omega}{2K_1}} z - \\ - \sigma_n) + \sum_{n=1}^{j} \sum_{m=1}^{v} \frac{1-A_m}{c_1\rho_1} \beta_m C^I_{m,n} \Bigg\{ \\ \Bigg\{ e^{-\beta_m z} \sin(n\omega\tau - \varepsilon_{m,n} - \partial_{m,n}) - \\ - e^{-\sqrt{\frac{n\omega}{2K_1}} z} \sin\Big(n\omega\tau - \varepsilon_{m,n} - \partial_{m,n} - \sqrt{\frac{n\omega}{2K_1}} z\Big) \Bigg\} \end{aligned}\right\} (10)$$

where $N_n = \left[\left\{ (A^t_n)^2 + (B^t_n)^2 \right\} \frac{her^2\, a_n + hei^2\, a_n}{her^2\, b_n + hei^2\, b_n} \right]^{\frac{1}{2}}$,

$her\, x = Re \left\{ H_0^{(1)}(x) \right\}$, $hei\, x = Im \left\{ H_0^{(1)}(x) \right\}$,

$a_n = \frac{2}{\mu} \sqrt{\frac{n\omega}{K_2}}$, $b_n = a_n \sqrt{1+\mu h}$,

$\sigma_n = \text{arctg} \frac{hei\, a_n}{her\, a_n} - \text{arctg} \frac{hei\, b_n}{her\, b_n} + \text{arctg} \frac{B^t_n}{A^t_n}$,

$C^I_{m,n} = \left[\left\{ (A^I_{m,n})^2 + (B^I_{m,n})^2 \right\} \left\{ (n\omega)^2 + (K_1\beta_m^2)^2 \right\}^{-1} \right]^{\frac{1}{2}}$

It is not difficult to find that the first sum of expression (10) reflects those changes of sea temperature which are the result of the changes of heat balance on the sea surface. The last changes are expressed by the air temperature.

The second sum describes sea temperature changes resulting from the absorption of the radiation which penetrates the water.

In conclusion, let us quote one of the examples of the comparison relating to the curves of daily variations of sea temperatures both observed and calculated.

For the demonstration of the suggested method we used the data concerning daily variations of temperature of the Black Sea surface summer radiation and air temperature.

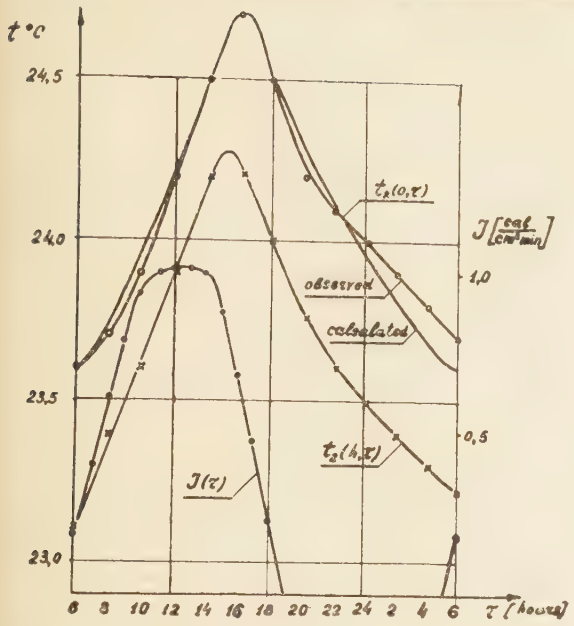


Fig. 1.— Variation of the solar radiation [I(τ)] and that of the sea surface temperature.

Figure 1 clearly shows both curves. Temperature of the sea surface — calculated and observed — coincides sufficiently well during the whole daily period, thus showing that the proposed method of calculation describes the process of the sea temperature's formation.

REFERENCES

(1) Kolesnikov, A., 1947, *Reports of the Academy of Sciences of the USSR*, **57** (2).

(2) ———, 1954, *News of the Academy of Sciences of the USSR*, Series of Geophysics No. 2.

(3) ——— and Pivovarov, A., 1955, *Reports of the Academy of Sciences of the USSR*, **102** (2).

DISCUSSION

K. HIDAKA: Could I see the original of your curve?

A.G. KOLESNIKOV: I will present it in my paper, we have data from both the Japan Sea and the Black Sea. However, this curve comes from Black Sea measurements.

K. WYRTKI: How deep have these daily variations been observed?

A.G. KOLESNIKOV: To the depth of 20-25 meters.

K. HIDAKA: What is the change with depth?

A.G. KOLESNIKOV: The amplitude diminishes with depth, but the curve has the same general character.

SEDIMENTS OF THE TRENCHES IN THE NORTHWESTERN PACIFIC

P.L. BEZRUKOV

Institute of Oceanology, Academy of Sciences of the USSR, Moscow, USSR.

Bottom sediments of the trenches are little investigated. Literature gives practically no information concerning the extension of sediments in trenches. Knowledge of the composition, distribution, and stratification of sediments in the trenches themselves and on their slopes is, however, necessary for understanding the general laws of sedimentation in the ocean as well as for elucidating the history of the development of the deepest depressions of its bottom.

In 1953-1955, the Institute of Oceanology of the Academy of Sciences of the USSR undertook, on board the *Vitiaz*, complex investigations of six trenches of the Pacific Ocean, namely, the western part of the Aleutian trench (from Attu Island to Bering Island), the Kurile-Kamchatka trench (throughout its whole extension), the northern part of the Japanese trench (south to 38° N. lat.), of the Idzu-Bonin trench (between 31° and 27° N. lat.), the northern part of the Marianas trench (between 25° and 23° N. lat.), and the Ryukyu trench (opposite the Togara and the Amami islands) *(1, 2, 3, 14, 15)*. In the course of these investigations, new data on bottom sediments were obtained.

Samples of sediments were taken from the slopes and the very bottoms of the trenches by means of bottom samples, core apparatus, and trawls. Valuable additional material on the distribution of sediments in trenches was also obtained by echograms. The total number of sediment samples taken from the trenches as deep as 6.5-10 km. was 46; 7 samples were taken from the Aleutian trench (with the lowest depth 7,276 m.); 27 samples from the Kurile-Kamchatka trench (the lowest depth being 9,980 m.); 2 samples from the Japanese trench (the lowest depth being 6,500 m.); 4 samples from the Idzu-Bonin trench (the lowest depth being 9,760 m.); 4 samples from the Marianas trench (the lowest depth being 7,676 m.); and 2 samples from the Ryukyu trench (the lowest depth being 6,785 m.). In addition to this, a lot of samples were obtained from lesser depths, from the slopes of the trenches as well as from the vicinity of the ocean bed. Cores of bottom sediments from the trenches were some tens of centimeters and up to 4.5 meters long; those taken from the marginal part of the ocean bed attained as much as 12 m. Investigations of the granulometric, petrographic, and mineralogical compositions of sediments were carried out in the laboratory. Studies were also made of their stratigraphy and of the distribution of the diatoms, as well as of such chemical compounds as $CaCO_3$, authigenic SiO_2, organic matter, Fe, Mn, and some other studies.

The explored trenches have some common morphological features. Stretching on the outer side of the belt of insular arcs, which are connected with the recent vulcanic zone, they all display a large linear extension, having at the same time a rather limited width; their slopes are steep and their bottoms are flat. The steepness of slopes on the average is 6-8°, but in some parts they are complicated by terraces as well as by still steeper, sometimes almost vertical ledges ranging from some hundreds of meters to some kilometers in height. These ledges are connected with some disjunctive discomformity. The flat bottoms of the trenches, from 5 to 30 km. wide, presents an accumulative plain. From the outer side of the bottom trenches along the ocean bed margin stretches a discontinuous chain of submarine swells, which rise several hundreds of meters above the average level of the bottom. Locally they are even higher.

These swells are crowned by single submarine volcanoes. Also, submarine uplifts are situated in the corners of the oceanic platform between the Aleutian and the Kurile-Kamchatka trenches as well as between the latter and the Japanese trench.

The character of deep trenches, their high seismic activity and their connection with the belt of recent volcanism permits one to consider them as recent geosynclines, being in the process of bending as well as being closely connected with the bottom fractures *(1, 11, 12)*.

Sediment is brought to the trenches from the side of insular chains, as well as through the straits between the islands from the Far Eastern seas. Sedimentation also proceeds biogenetically from oceanic waters. Finally sedimentation to a certain extent proceeds from the submarine denudation of the slopes of the trenches.

Let us first consider the distribution of recent sediments in the three northern trenches, namely, the Aleutian, the Kurile-Kamchatka, and the Japanese trenches which were more thoroughly studied.

On the slopes of these trenches from the side of the insular ridges are developed noncarbonate terrigene and volcanic sediments, the border line of sands being deepest in front of the deep Kurile straits, often running as deep as 3-3.5 km; the border line of silty muds (Md = 0.1-0.01 mm.) in places goes down to 5.5 km. Small spots of silty muds are encountered as deep as 7.5 km. On some places on the slopes, muddy sediments are deposited 1.5-2 km. deep. On the bottoms of the trenches, muds frequently containing up to 80-92% of the fraction < 0.01 mm. predominate.

In the mineral composition of sands and sandy-silty fractions of silty sediments, owing to the proximity of the andesite volcanic belt, there is a predominance of plagioclases, hipersten, augite, basaltic hornblende, volcanic glass, and titanomagnetite; quartz and potash feldspar are in very small quantities *(9)*. Accessory minerals found chiefly off Kamchatka and Hokkaido are diopside, actinolite, epidote, titanite, rutile, zirconium, glauconite and some others.

On the outer slopes of the trenches, argilaceous muds are developed. Farther oceanwards on the above mentioned submarine uplifts, above which the water turbulence increases, they again are changed by silty muds. Thus the most finegrained sediments are deposited on the bottoms of the trenches, whereas on their slopes the sediments become coarser. On the steep ledges of the slopes there often occur at various depths outcrops of clays and argillites, whereas on bottom surfaces there are abundant quantities of fragments and cobbles of tight clay obviously transported there as a result of bottom slides.

On the slopes as well as on the bottom of the trenches there are dessiminated fragments of pumice pebbles. In the Kurile-Kamchatka and the Aleutian trenches there are pebbles of various igneous and sedimentary rocks, seemingly transported here from land by ice.

The argillaceous muds on the bottom and on the slopes of the northern trenches are enriched by the diatomic remains and display a high content of authigenic silica. In the western part of the Aleutian trench, the maximal authigenic SiO_2 content in the surface layer of these muds attains 18%; in the northern part of the Japanese trench, it reaches 12%; in the Kurile-Kamchatka trench, it goes up to 20%; and in front of the Little Kurile islands, on the northwestern slope, it even runs up to 36%. Sideways off the insular chain, with the gradual increasing of the coarseness of sediment particles as well as in the ocean bed with the transition into the area of subtropical waters, the authigenic SiO_2 content in sediments decreases to a few per cent. In the upper layer of sediments of the Aleutian and Kurile-Kamchatka trenches, there is a predominance of boreal oceanic and neretic species of diatomic flora *(5)*.

It is very characteristic of clay deposits to have an increased content of organic matter as compared with sediments from the slopes. In the Kurile-Kamchatka trench, the maximal organic carbon content of the upper layer attains 1.5%; towards the Kamchatka and the Kurile, along with the coarsening of the sediment content, it gradually decreases to 0.5 - 0.1% and even less. Towards the ocean, the organic carbon content also decreases to 0.5-0.1%, this being true not only in silty but in argillaceous muds as well. This is due to the decrease of the biomass of the phytoplankton in the offshore regions. On the bottom of the western part of the Aleutian trench, the organic carbon content of sediments does not exceed 0.8% and goes down on both slopes also.

The surface layer of argillaceous mud deposits on the bottom of all three trenches is coloured in brown by the oxides of Fe and Mn. The thickness of the layer varies from 1 to 12 cm., being generally less off Kamchatka. It is underlain by grey muds of the reducing zone containing hydrotroilite; somewhat lower there is pyrite and free H_2S *(1, 8)*. Farther off from the trenches in the marginal zones of the ocean bed, the thickness of the oxidized layer increases to 0.2 - 0.6 m. and still farther it goes up to 3 - 5 m. and even more. There this layer displays a typical red clay. Under it, in the sediments of the reducing zone, iron sulfide content is insignificant and H_2S is absent. The increase in the thickness of the oxidized layer oceanwards depends upon the decrease in the quantity of the organic matter brought to the bottom, the decomposition of which is in relation with the reduction processes proceeding in the sediment thickness.

On the bottom of the Kurile-Kamchatka and Aleutian trenches, the Fe content of the surface layer of the sediments varies from 3.5 to 7%; the Mn content varies from 0.05% to 2.0% and V_2O_5 varies from 0.01 to 0.03%. In the sands in the upper parts of the slopes as well as on the shelves of the islands, the Fe concentration

increases, in places running up to 10% and the Mn content varies from 0.1 to 0.5%. The sands are also enriched by vanadium (0.03-0.05 V_2O_5) and by titanium (0.5-2.9% TiO_2) *(6, 7)*. From the outer side of the trenches in the deposits of the ocean bed, the Fe content varies from 2.5 to 5.5%; the Mn from 0.1 to 4.3%; the V_2O_5 from 0.01 to 0.02%. The enrichment of sediments by iron, vanadium, and titanium basically depends upon their coming from igneous rocks of insular chains, whereas the enrichment by manganese depends upon its secondary migration into the oxidation zone during the diagenesis.

The investigation of cores of muddy sediments from the bottom of the Aleutian and the Kurile-Kamchatka trenches has shown that they contain irregular amounts of thin layers (from 0.5-1 mm. to 1-3 cm.) of volcanic ash, with silt or sand grade.

The character of the sequence of layers has clearly shown a graded bedding peculiar for the deposits of turbidity currents. The cores also give evidence of a change of the quantitative and qualitative composition of the diatoms, of the content of authigenic SiO_2, of the organic matter, and of the $CaCO_3$.

On the basis of the study of these changes in separate cores, up to four horizons were traced, the upper one apparently corresponding to Holocene, the second to the epoch of the last glaciation, and the lower ones corresponding to the more ancient stages of the Pleistocene. The same horizons, but displaying a greater thickness, were traced in the deposits of the Okhotsk and the Bering seas *(4)* thus indicating the existence of common features in the recent history of these seas and the northern part of the Pacific.

The most marked in both trenches as well as in the adjoining part of the ocean bed east of Kamchatka is the third horizon, whose sediments is composed of higher organic carbon content humic matter, bitumen, vegetative pigments, authigenic SiO_2, and $CaCO_3$ *(10)*. This horizon may correspond to the last interglacial epoch. Off the trenches oceanwards, due to the decreasing rate of sedimentation, there is a decrease of its distance from the bottom surface (from 1.2 to 0.3 m.) and of its thickness as well (from 0.8 to 0.3 m.).

The Idzu-Bonin and Marianas trenches are distinguished from the northern ones by their situation farther off the continent and by their belonging to another climatic zone. The latter applies also to the Ryukyu trench. Their sediment composition is, therefore, quite different. On the slopes of the trenches from the side of insular chains, volcanogenic sands and various carbonate sediments are developed, chiefly there are to be found coral and foramineferous sands as well as silty muds frequently containing more than 50% of $CaCO_3$. Lower, at 4.5-5 km., they are replaced by noncarbonate ($<0.5\%$ $CaCO_3$) brown argillaceous muds whose organic carbon content does not exceed 0.3%. On the bottom of the Idzu-Bonin and Ryukyu trenches, there were found grey muds of the reducing zone. On the outer slopes of the trenches there are widely spread brown argillaceous muds of the "red clay" type, whereas carbonate sediments are found in some uplifts. We have not come across any siliceous sediments in trenches under description.

One should observe, however, that in the southern part of the Marianas trench there are described diatomic muds consisting of folds of warm water *Ethmodisus rex (13)*. The distribution of this form differs essentially from that of cold water diatoms, composing diatomic muds in the northern part of the ocean.

On the slopes of Southern trenches, there are denuded areas, and on the bottom there are fragments and boulders of tight clay, seemingly sliding from the slopes. In samples of bottom waters taken from the 6-7 km. depth, there was observed a marked increase in the quantity and a change of water-suspended composition, thus showing a submarine denudation of the slopes.

Pyroclastic material, pebbles, and pumice fragments are found in great quantities in sediments as well as fine interlayers of ashes. In their mineral composition there is also an abundance of plagioclase, hipersten, volcanic glass, and magnetite. In separate samples taken from the slopes of the Idzu-Bonin trench there was observed a rise in the Fe (up to 6.5%) content.

In the trenches of the northwestern part of the Pacific ocean, complex processes of terrigenic, volcanic, and biogenic sedimentation are proceeding. The unsteadiness of these processes in time is expressed in the lamination of sediments of various composition. The principal factors determining the character of lamination are climatic changes, the recurrence of volcanic eruptions and submarine earthquakes provoking sliding, turbulence, and redeposition of previously deposited material.

The influence of climatic factors upon recent sedimentation is expressed in the facial replacement, on the slopes of more northern trenches,

of carbonate biogenic sediments by siliceous ones as well as by the appearance here of coarse fragmental material of glacial deposition.

In all the trenches the sedimentation proceeds irregularly; its maximal average speed being off the Kamchatka and its minimal one being in the Idzu-Bonin and Marianas trenches situated farther off from the continent.

In concluding, one should mention that during the 1957 expedition of the *Vitiaz*, some other trenches of the Pacific ocean were also investigated, namely: the Bougainville, the Palau, and the southern part of the Marianas trench. In the latter, there was found a new maximal world ocean depth of 10,960 m. The study of all the collected materials will enlarge our knowledge of sedimentation and of the history of the development of the deepest depressions of the ocean bottom.

REFERENCES

(1) Bezrukov, P.L., 1955, *Trans. Inst. Ocean. Acad. Sci. USSR*, **12**.

(2) ———, 1956, *Bull. Sov. Seismol. Acad. Sci. USSR*, **2**.

(3) ———, 1957, *C.R. Acad. Sci. USSR*, **114** (2).

(4) ——— and Lisitzin, 1957, *Trans. Commission Quatern. Period. Acad. Sci. USSR*, **13**.

(5) Jouse, A.P. and Sechkina, T.V., 1955, *Trans. Inst. Ocean. Acad. Sci. USSR*, **12**.

(6) Ostroumov, E.A., 1956, *C.R. Acad. Sci. USSR*, **107** (3).

(7) ——— and Silina, O. M., 1952, *C.R. Acad. Sci. USSR*, **96** (2).

(8) ——— and Shilov, V. M., 1956, *C.R. Acad. Sci. USSR*, **106** (3).

(9) Petelin, V. P., 1955, *Trans. Inst. Ocean. Acad. Sci. USSR*, **13**.

(10) Romankevich, E.A., 1957, *C.R. Acad. Sci. USSR*, **116** (3).

(11) Udintzev, G.B., 1955, *Trans. Inst. Ocean. Acad. Sci. USSR*, **12**.

(12) ———, 1956, *Bull. Sov. Seismol. Acad. Sci. USSR*, **2**.

(13) Wiseman, J.D.H. and Hendey, N.I., 1953, *Deep-Sea Research*, **1** (1).

(14) Zenkevich, L.A., 1955, *Trans. Inst. Ocean. Acad. Sci. USSR*, **12**.

(15) ———, 1956, *Deep-Sea Research*, **4** (1).

Symposium: ***Biological Oceanography***

INVESTIGATIONS OF BOTTOM FAUNA OF THE FAR EASTERN SEAS AND ADJACENT PART OF THE PACIFIC†

L.A. ZENKEVITCH

Institute of Oceanology, Academy of Sciences of USSR, Moscow, USSR.

(*Abstract*)

Since 1949 the Institute of Oceanology of the Academy of Science of USSR has carried out intensive oceanologic investigations in the Sea of Japan, Sea of Okhotsk, and Bering Sea and adjacent parts of the Pacific. The work of the Institute embraces an area of nearly 7.5 million sq. km. extending from the littoral to the greatest depths.

Bottom fauna studies have been carried out over the region. Nearly 1,500 stations, working qualitatively and quantitatively have yielded about 300 new species and 30 new genera.

Charts of the quantitative distribution of bottom fauna demonstrate a range of biomass from over one kilogramme in the shallow waters to several hundred milligrammes in the deep regions of the open ocean.

Charts of quantitative biocenotic distribution of bottom fauna were worked out for the whole region investigated.

For the main regions of fishing in the Far Eastern seas and for the East Coast of Kamchatka, charts of the distribution of the total biomass of bottom fauna and charts of biomass of bottom fauna consumed by benthofagous fishes have been drawn.

† Presented by Dr. Eupraxie Gurjanova.

STUDY OF ABYSSAL BOTTOM FAUNA IN THE NORTHWEST PART OF THE PACIFIC BY *VITIAZ*†

L.A. ZENKEVITCH

Institute of Oceanology, Academy of Sciences of USSR, Moscow, USSR.

(Abstract)

The R/S *Vitiaz* has obtained large collections of abyssal bottom fauna from the northwest part of the Pacific Ocean during operations commencing in 1949.

Sampling was carried out by means of trawling and bottom sampling. In 1949 a sample collected from the Kurile-Kamchatka trench at a depth of 8,100 meters established the existence of abyssal fauna.

The collections contained a large number of organisms new to science representing new species, genera, families, and one new phylum, from Pogonophora.

The collections have permitted the establishment of a new vertical zonation as follows:

Surface zone	0— 200 m.
Transitional zone	200— 600 m.
Abyssal zone	600—6,000 m.
Ultra-abyssal zone	> 6,000 m.

This zonation appears to be dependent upon the habits of the bottom fauna and related to the quantities of material in suspension in the deep water layers and to the character of the bottom sediments.

The collections have permitted an assessment of the distribution of bottom fauna in terms of biomass in grammes per sq. meter. It was established that remoteness from the shore-line controls the biomass value and that the depth factor is subordinate to this.

It is suggested that the differences between faunas in the several deep sea trenches may serve as criteria for the assessment of the age of formation of the trenches and the origins of their populations.

† Presented by Dr. Eupraxie Gurjanova.

DISCUSSION

N.A. MEINKOTH: Would you please comment on the new phylum which has been described?

E. GURJANOVA: It is the phylum Brachiata described by A.W. Ivanov and originally reported as an order, Pogonophora.

D.J. ROCHFORD: What method was used to sample the ultra-abyssal zone?

E. GURJANOVA: A new sampling method which has been discussed in the Russian literature as the system "Ocean."

INVESTIGATIONS OF THE BOTTOM FAUNA OF THE FAR EASTERN SEAS OF THE USSR.

P.V. USHAKOV

Zoological Institute of the Academy of Sciences of the USSR, Leningrad, USSR.

The Far Eastern seas of the USSR (Sea of Japan, Sea of Okhotsk, and Bering Sea) were the object of systematic and detailed research, even before the war, on the initiative of Professor K.M. Derjugin. In the postwar period, the research work in the seas of the Far East was considerably enlarged. In the period between 1947 and 1949, extensive investigations were pursued by the expedition of the Zoological Institute of the Academy of Sciences of the USSR (Leningrad) together with the Pacific Scientific Research Institute of Fisheries and Oceanography (Vladivostok) in the region of South Sakhalin and southern Kuril Islands. The results of this expedition were published in 1955/56 in the form of a two-volume atlas of large scale charts of this region showing in detail the distribution of principal biocenoses and some of the most characteristic species of sea animals and plants which could serve as indicators of hydrologic and other conditions. From the beginning of 1949, extensive and detailed oceanographic investigations are still pursued in the seas of the Far East by the Institute of Oceanology of the Academy of Sciences (Moscow) on its research ship *Vitiaz*.

Some of the results of the investigation of the fauna of the Far Eastern seas were published in the series *Fauna of the USSR, Investigation of the Far East seas of the USSR, Transactions of the Institute of Oceanology*, and in many other publications. A list of principal literature published in Russian after 1952 and dealing with the bottom fauna in the Far East seas is to be found at the end of this paper.

At present the number of species of invertebrates existing in the Far East seas is as follows: Foraminifera 600, Spongia 150, Hydrozoa 240, Polychaeta 450, Bryozoa over 200, Cumacea 65, Isopoda 175, Amphipoda over 500, Decapoda 175, Pantopoda 68, Mollusca about 500, Echinodermata 275, Tunicata 75.

Of special interest are the original invertebrates Pogonophora discovered primarily in the seas of the Far East and found subsequently in other regions of the World Oceans. According to the investigations of A. Ivanov (1955) these animals ought to be classified as a new type of invertebrates (Brachiata). A large place in the fauna of the Far East seas is taken by the endemic species. In some of the groups of bottom fauna their number exceeds 25%. Moreover, in some of the groups of bottom fauna (as for instance among the Polychaeta) there are many species which may be found exclusively in the seas of the Far East and in the Arctic seas. At the opposite lying coast of northern America these species, common both to Arctic and Far East seas, are very scarce. The high endemism of the fauna is so specific for the seas of Far East that it compels us to consider this fauna as an original and independent faunistic subdivision of the North Pacific boreal zone.

The composition of the bottom fauna and its distribution have many specific particularities in different regions of the Sea of Japan, Sea of Okhotsk and Bering Sea, owing to the extreme diversity of their physical and geographical conditions. In particular, the vertical distribution of fauna in these seas is widely different depending on the degree of their isolation from the influence of Pacific waters.

Sea of Okhotsk has very characteristic vertical zones of fauna distribution, closely bound up with the stratification of water masses. On the continental plateau (0-200 m.) we find two sharply defined horizons: the upper one, up to the depth about 50 m. with great variations of temperature according to seasons, and the lower horizon with a constant low temperature mostly below the zero (the so-called "layer of eternal congelation"), in the depth of 50-200 m. The upper horizon is characterized by algae associations. The lower horizon has a population of forms found usually in cold waters and typical for the same (as for instance the biocenose *Ophiura sarsi* on the muddy bottom). In the region of continental slope—the bathyal (from 200 to 2,000 m.) — we find also two very definite vertical zones: (1) the upper part of the bathyal (up to the depth of 750 m. approximately) has a rather rich and various population (biocenose *Brisaster* and others), and (2) the lower part of the bathyal where the population is considerably poorer, owing to the decrease of oxygen

in these depths (the "Okhotsk depression"). The depths over 2,000 m. in the Sea of Okhotsk have really abyssal fauna (*Psychropotes raripes*, *Urechinus naresianus* and others), brought into it from the adjacent regions of the Pacific through the deep straits of Kuril ridge.

Bering Sea has about the same scheme of vertical zones. But in the Sea of Japan we meet with another situation. As the trench of the Sea of Japan is separated from Pacific Ocean by shallow straits the real abyssal fauna is absent and we find here instead a local fauna descended from the coastal regions and having acquired during the evolution some traits of abyssal fauna (as for instance *Harmothoë derjugini*). The great depths in the Sea of Japan are typically "pseudo-abyssal."

Some of the animals communities existing in the seas of Far East may sometimes, under the influence of local conditions, pass from one zone into another. Thus biocenose *Stegophiura nodosa*, an aboriginal of shallow waters of Arctic seas, is found in Bering Sea in the depths of 5-25 m. while at the southeastern coast of Kamchatka and in the Sea of Okhotsk the same biocenose exists in the depths of 30-100 m., but here it is less pronounced than in the northern part of Bering Sea. In the Sea of Japan single specimens of the biocenose *Stegophiura nodosa* have been discovered in the depths of 80-200 m. The same was observed with reference to the biocenose *Ophiurai*; *sars* in the northern part of Bering Sea it has been found in the depth of 25-60 m., in the Sea of Okhotsk in waters 100-200 m. deep, while in the Sea of Japan we have found but rare specimens of this biocenose descended to the depth of 200-600 m. Thus, in the Sea of Japan we observe, as a rule, the regular descent to greater depths of numerous cold-water species which populate the shallow waters of the adjacent parts of the Sea of Okhotsk and the Bering Sea. This can be explained by the fact that the temperature of deep waters in the Sea of Japan is lower than in the Sea of Okhotsk and the Bering Sea. The deep waters of the Sea of Japan by their conditions of temperature may be rightly called "The Arctic deeps of the Pacific."

The most obvious and striking changes of biocenose may be observed in the tidal zone as the fauna here is under the influence both of the hydrological conditions and of the local climate factors. In the tidal zone of the Sea of Japan and in the upper horizon of its sublittoral, the biocenose *Zostera* is very rich, but it becomes very scarce in the Sea of Okhotsk. Instead, in the tidal zone of the Sea of Okhotsk, in its bay, we find a rich population of *Fucus*, very similar to the population in Barents Sea. This fact enables us to speak not only of amphiboreal distribution of single species, but of amphiboreal distribution of whole biocenoses as well.

The tidal zone in the most northern part of Bering Sea (the Arctic type of tidal zone) is nearly devoid of specific sea animals.

The continental shelf of the northwestern part of Sea of Japan, of the northern part of Sea of Okhotsk and the northwestern part of Bering Sea, owing to the peculiarities of their hydrological conditions, is populated mostly by cold-water fauna. This cold-water fauna meets in all the Far East seas the warm water fauna, carried here by the warm current from the south. This meeting of two different fauna may be observed in the Peter the Great Bay. Another place of meeting of both fauna of different origin lies in the region of La Perouse (Soya) Strait. A number of typical subtropical species, carried by the warm waters of Tsushima current along the western coast of Japan, reach La Perouse Strait, but the majority of these stop there without penetrating further northward and only rare specimens spread along the western coast of South Sakhalin. The region of La Perouse Strait is the frontier between the subtropical fauna of the southeastern part Sea of Japan and the cold-water fauna of its northwestern half.

The exchange of fauna between the Sea of Japan and the Sea of Okhotsk through La Perouse Strait is rather one-sided and directed towards Sea of Okhotsk. The representative species from Sea of Japan passing through La Perouse Strait into the adjacent parts of Sea of Okhotsk are as follows: Polychaeta—*Aphrodita australis*, *Sigalion mathildae*, *Trypanosyllis misakiensis*, *Nereis japonica*, *Arabella tricolor*, *Driloneris filum*, *Andouinia tentaculata*, *Schistocomus sovjeticus*, *Polymnia trigonostoma;* Crustacea— *Pandalus latirostris*, *Pandalus meridionalis*, *Eualus japonica*, *Blepharipoda japonica*, *Hemigrapsus penicillatus*, *Hemigrapsus sanguinea*, *Pennixa rathbuni*, *Doclea bidentata;* Mollusca—*Pecten yessoensis*, *Chlamys swiftii*, *Chlamys crythrocomatus;* Echinodermata —*Patizia pectinifera*, *Lysastrosoma anthostricta*, *Aphelasterias japonica*, *Stichopus japonicus*, *Echinarachnius griseus*, and many others.

All these species have been found only in the region of Sea of Okhotsk lying in the immediate vicinity of La Perouse Strait. The fauna of the above mentioned part of Sea of Okhotsk is more like the fauna of Sea of Japan than the fauna of

any other part of Sea of Okhotsk. Some of the species specific to Sea of Okhotsk penetrate into the northwestern part of Sea of Japan through La Perouse Strait, but in very insignificant quantities. The most favourable conditions for the penetration of Sea of Okhotsk species into Sea of Japan are in winter on the narrow shelf under the coast of Sakhalin at the time when Tsushima current decreases and cold currents from Sea of Okhotsk gather strength.

Some of the above mentioned species of Sea of Japan fauna are carried by the Soya current in the region of South Kuril islands. Here the species of Sea of Japan fauna meet with some of the species characteristic to cold waters and brought here from the north by the cold currents flowing along the coast of Kuril Islands. The clearly marked frontier between these two faunas lies in the Catherine Strait and appears to coincide with the abrupt change of the bottom isotherms. By its origin the fauna of North Kuril Islands approaches very closely the fauna of Bering Sea.

The estuary of Amur at present has no importance in the exchange of fauna between Japan and Okhotsk seas. Owing to its specific conditions (shallow and brackish waters) the estuary of Amur with its brackish-water population is a clearly defined faunistic barrier.

A well defined place of meeting of two different faunas lie in the region of Bering Strait. The warm waters of Bering Sea carry into the southern part of Chukotsk Sea many Pacific species which may serve as good biological indicators of the influence of Bering Sea upon Chukotsk Sea. In particular the following species of Pacific fauna penetrate into the southern half of Chukotsk Sea: Polychaeta—*Gattyana ciliata*, *Arcteobea anticostiensis*, Bryozoa—*Porella saccata* v. *beringi;* Crustacea—*Melita quadrispinosa*, *Harpinia gurjanovae*, *Spirontocorella macilenta*, *Spirontocaris spina intermedia*, *Sclerocrangon communis*, *Pandalus goniurus*, *Chionoecetes opilio;* Mollusca—*Mysella planata;* Echinodermata—*Amphiodia craterodmeta*, *Psolus peronii;* Tunicata—*Chelyosoma orientale*, *Placentela crystallina*, etc. Some of these species were found in Chukotsk Sea as far as Herald Island. The boundary line of distribution of most of the Pacific species follows closely the average border line of floating ices in this sea towards the end of the hydrological summer. The Arctic species penetrate from Chukotsk Sea into the northern half of Bering Sea in very small numbers and, as a rule, they remain in Anadyr Bay without advancing further southwards (for instance *Eualus gaimardii belcheri*). The frontier between the Arctic zone and the North Pacific boreal zone passes in the region of Bering Strait.

The distribution of cold-water and warm-water species in Japan, Okhotsk and Bering seas is subject to continuous changes depending on general fluctuations of hydrological conditions. Thus, between 1920 and 1938 there was an increase in number of warm-water species (for the most part among the fishes of Sea of Japan). But after 1939 the warm-water species became less numerous owing to an abrupt fall of temperature. Actually a new increase in the number of warm-water species has been noted as a consequence of a new change of temperature showing a tendency to rise.

BIBLIOGRAPHY

Akimushkin, I.I., 1927, About the fauna of Cephalopoda in the Far East seas of the USSR. *Investigation of the Far East Seas of the USSR.* (Issledovanija Dalnevostochnich morej), **4**: 127-148.

Androssova, E.I., 1953, Bryozoa of the order Cheilostomata from the Japan sea. *Trans. of Conferences on Problems and Themes of the Zoological Institute of the Acad. of Sci. of the USSR* (Trudi problemnich i tematicheskich sovestchanij Zoologicheskogo Instituta AN SSSR), **4**: 77-80.

Annenkova, N.P., 1952, *Polychaeta of Chukotsk Sea and Bering Strait. Extreme Northeast of the USSR* (Krajnij Severovostok Sojuza SSR), II. Moscow: Acad. of Sci. of the USSR. 112-137.

Baranova, Z.I., 1955, New species and subspecies of Echinodermata from Bering sea. *Trans. of the Zool. Instit. of the Acad. of Sci. of the USSR* (Trudi Zoologicheskogo Instituta AN SSSR), **18**: 334-342.

————, 1957, Echinodermata of Bering sea. *Investigation of the Far East Seas of the USSR* (Issledovanija Dalnevostochnih morej), **4**: 149-266.

Birstein, J.A. and Vinogradov, L.G., 1953, New data on the Decapoda fauna in Bering Sea. *Zool. Journal* (Zoologicheskij zhurnal), **32** (2): 215-228.

Bulycheva, A.I., 1952, New species of Amphipoda Gammaridea from the Japan sea. *Trans. of the Zool. Institute of the Acad. of Sci. of the USSR* (Trudi Zoologicheskogo Instituta AN SSSR), **12**: 195-250.

Bulycheva, A.I., 1957, Amphipoda of the northwestern part of Japan sea. *Investigation of the Far East Seas of the USSR* (Issledovanija Dalnevostochnih morej SSSR) **4**: 85-106.

———, 1957, Amphipoda, Talitroidea of the seas of the USSR and of adjacent waters, *Keys to the Fauna of the USSR* (Opedeliteli po faune SSSR), No. 65: 1-186.

Djakonov, A.M., 1952, Echinodermata of the abyssal depths from the waters of Kamchatka. *Investigation of the Far East Seas of the USSR* (Issledovanija Dalnevostochnih morej SSSR), **3**: 116-130.

———, 1952, *Echinodermata of Chukotsk Sea and Bering Strait. Extreme Northeast of the USSR* (Krajnij Severo-Vostok Sojuza SSR), VI. Moscow: Acad. of Sci. of the USSR, 286-310.

Djakonov, A.M., 1955, Ophiura of the Seas of the USSR. *Keys to the Fauna of the USSR* (Opredeliteli po faune SSSR), No. 55: 1-136.

Galkin, Y.I., 1953, Materials on Characteristics of Mollusca Fauna in Aniva Bay, Okhotsk Sea. *Trans. of the Zool. Institute of the Acad. of Sci. of the USSR* (Trudi Zoologicheskogo Instituta AN SSSR), **13**: 242-249.

———, 1955, Mollusca: Gastropoda, Trochidae of the Far East and Arctic seas. *Keys to the Fauna of the USSR* (Opredeliteli po faune SSSR), No. 57: 1-132.

Gorbunov, G.P., 1952, *Bivalvia of Chukotsk Sea and Bering Strait. Extreme Northeast of the USSR* (Krajnij Severo-Vostok Sojuza SSR), II. Moscow: Acad. of Sci. of the USSR, 216-279.

Gurjanova, E.F., 1952, On the fauna of Crustacea—Malacostraca in the Northern half of Pacific Ocean. *Investigation of the Far East Seas of the USSR* (Issledovanija Dalnevostochnih morej SSSR), **3**: 113-115.

———, 1952, *Crustacea-Malacostraca of Chukotsk Sea and Bering Strait. Extreme Northeast of the USSR* (Krajnij Severo-Vostok Sojuza SSR), II. Moscow: Acad. of Sci. of the USSR, 167-215.

———, 1952, New species of Amphipoda (Amphipoda-Gammaridea) from the Far East Seas. *Trans. of the Zool. Instit. of the Acad. of Sci. of the USSR* (Trudi Zoologicheskogo Instituta AN SSSR), **12**: 171-194.

———, 1953, New supplement to the fauna of Amphipoda of the Far East seas. *ibid.*, **13**: 216-281.

———, 1955, New species of Amphipoda (Amphipoda Gammaridea) from the northern half of Pacific Ocean. *ibid.*, **18**: 166-218.

———, 1955, On the fauna of Isopoda in the Pacific Ocean. IV. New species of Valvifera from the region of Kuril-Sakhalin. *ibid.*, **21**: 208-230.

Ivanov, A.W., 1955, On Pogonophora as a special type of Deuterostomia-Brachiata A. Ivanov, Phylum nov. *Reports of the Acad. of Sci. of the USSR* (Dokladi Academii Nauk SSSR), **100** (3): 595-596.

———, 1956, About the systematic place of Pogonophora. *Zool. Journ.* (Zoologicheskij zhurnal), **35** (12): 1863-1972.

Jakovleva, A.M., 1952, Mollusca Loricata from the seas of the USSR. *Keys to the Fauna of the USSR* (Opredeliteli po faune SSSR), No. 45: 1-197.

Kluge, G.A., 1953, On the distribution of *Kinetoskias* Danielssen (Bryozoa). *Trans. of the Zool. Institute* (Trudi Zoologicheskogo Instituta), **31**: 210-215.

———, 1952, *Bryozoa of Chukotsk Sea and Bering Strait. Extreme Northeast of the USSR* (Krajnij Severo-Vostok Sojuza SSR), II. Moscow: Acad. of Sci. of the USSR. 138-168.

Kobjakova, Z.I., 1956, The specificity of distribution of Decapoda in the region of South Sakhalin. *Trans. of Conferences on Problems and Themes of the Zool. Institute* (Trudi problemnih i tematicheskih sovestchanij Zoologicheskogo Instituta), **6**: 47-64.

Koltun, V.M., 1955, New species and genus of Spongia, *Cornacuspongius* from the Okhotsk and Bering seas. *Trans. of the Zool. Institute of the Acad. of Sci. of the USSR* (Trudi Zoologicheskogo Instituta AN SSSR), **18**: 13-18

Konzhukova, E.D., 1957, Brachiopoda of the Far East seas of the USSR. *Investigation of the Far East Seas of the USSR* (Issledovanija Dalnevostochnih morej SSSR), **4**: 5-84.

Kulichkova, V.A., 1954, About the biology of Kamchatka crab at the southeastern coast of Sakhalin. *Bull. of the Pacific Scientific Research Institute of Fisheries and Oceanography* (Izvestija Tihookeanskogo nauchno issledvatelskogo Instituta rybnogo hoziajstva i okeanographii), **42**: 136-148.

Kussakin, O.G., 1955, About the systematic of some species of *Idothea* Fabr. (Isopoda, Valvifera) in the Far East seas of the USSR. *Trans. of the Zool. Institute of the Acad. of Sci. of the USSR* (Trudi Zoologicheskogo Instituta AN SSSR), **18**: 219-237.

———, 1956, On fauna and flora of the tidal zone of Kunashir Island. *Trans. of Conferences on Problems and Themes of the Zool. Institute* (Trudi problemnih i tematicheskih sovestchanij Zoologicheskogo Instituta) **6**: 98-115.

Lindberg, G.U., 1953, *The Distribution of Fishes and Geological History of the Far East Seas.* Articles on the general questions of Ichtyology (Ocherki po obstchim woprosam ichtiologii). 41-57.

———, 1955, *The Quaternary Period in the Light of Biogeographical Data.* Leningrad: Zool. Institute of the Acad. of Sci. of the USSR. 1-334.

Lomakina, N.B., 1952, New and zoogeographically interesting species of *Cumacea* in the Far East seas. *Zool. Journal* (Zoologicheskij zhurnal), **31** (2): 244-278.

———, 1955, *Pavlovskeola campylaspoides*— new species of Cumacea, Nannastacidae. *Trans. of the Zool. Institute of the Acad. of Sci. of the USSR* (Trudi Zoologiches kogo Instituta AN SSSR), **21**: 190-192.

———, 1956, Cumacea of the Far East seas. *idem.*, **18**: 112-165.

Markovskaja, E.B., 1952, About the biology of *Mytilus* in Peter the Great Bay. *Bull. of the Pacific Scientific Research Institute of Fisheries and Oceanography* (Izvestij Tihookeanskogo Instituta rybnogo hoziajstva i okea nographii), **37**: 163-174.

Mikulich, L.V., 1954, The food of flat-fish at the coast of South Sakhalin and South Kuril islands. *Bull. of the Pacific Scientific Research Institute of Fisheries and Oceanography* (Izvestija Tihookeanskogo Instituta rybnogo hoziajstva i Okeanographii), **39**: 135-236.

Mokijevskij, O.B., 1953, On the fauna of the littoral of Okhotsk sea, *Trans. of the Institute of Oceanology* (Trudi Instituta Okeanologii), **8**: 167-197.

———, 1954. The quantitative distribution of the deep-sea bottom fauna in Japan sea, *idem.* **8**: 147-163.

———, 1956, Some specific traits of the littoral fauna at the continental coast of Japan Sea. *Trans. of the Conference on Problems and Themes of Zool. Institute* (Trudi problemnih i tematicheskih sovestchanij Zoologicheskogo Instituta), **6**: 116-121.

Naumov, D.V., 1952, A new specie of the genus *Anthomastus* Verrill (Alcyonaria) from the region of Kuril ridge. *Zool Journal* (Zoologicheskij zhurnal), **31** (2): 238-243.

———, 1955, New genus and species of Hydroidea from the Far East seas. *Trans. of the Zool. Institute of the Acad. of Sci. of the USSR* (Trudi Zoologicheskogo Instituta AN SSSR), **18**: 19-25.

Pogankin, M.V., 1952, On the ecology of Echinodermata from Peter the Great Bay. *Bull. of the Pacific Scientific Research Institute of Fisheries and Oceanography* (Izvestija Tihookeanskogo nauchno-issledovatelskogo Instituta rybnogo hoziajstva i okeanographii), **37**: 175-200.

Rjabinina, N.V., 1952, *Carditacea from Chukotsk Sea and Bering Strait. Extreme Northeast of the USSR* (Krajnij Severo-Vostok Sojuza SSR) II. Moscow: Acad. of Sci. of the USSR. 279-285.

Skalkin, V.A., 1957, A new species of Acsidia from Pacific Ocean, *Syncarpa longicaudata* sp. n. (fam. Styelidae). *Zool. Journal.* (Zoologicheskij zhurnal), **34**: (2): 287-299.

Skarlato, O.A. 1956, On the biogeography of Far East seas of the USSR on the basis of the bivalve Mollusca investigation. *Trans. of Conferences on Problems and Themes of Zool. Institute* (Trudi problemnih i tematicheskih sovestchanij Zoologicheskogo Instituta), **6**: 83-92.

———, 1953, *Bivalve Mollusca (Anisomyaria and Eulamellibranchiata Heterodonta) from the Far East Seas of the USSR.* (Abstract of dissertation). Zoological Institute of the Acad. of Sci. of the USSR. 1-14.

Sokolov, I.I., 1953, Halacaridae, II. *Fauna of the USSR.* New series, No. 53: 1-200.

Sokolova, M.N., 1954, *The Food and Feeding Groups of Deep-Sea Benthos in the Far East Seas.* Abstract of dissertation. Institute of Oceanology of the Acad. of Sci. of the USSR, 1-16.

———, 1956, The food of deep-sea benthos. *Reports of the Acad. of Sci. of the USSR* (Dokladi Academii Nauk SSSR) **110**(6): 1111-1114.

———, 1956, On the distribution of deep-sea benthos. The influence of microrelief and other factors on feeding groups of sea-bottom invertebrates. *Reports of the Acad. of Sci. of the USSR* (Dokladi Akademii Nauk SSSR), **110** (4): 692-695.

Stchedrina, E.G., 1952, About the distribution of Foraminifera in Japan sea. *Reports of the Acad. of Sci. of the USSR* (Dokladi Akademii Nauk SSSR), **87** (3): 505-508.

———, 1952, *Foraminifera of Okhotsk Sea and Bering Strait. Extreme Northeast of the USSR* (Krajnij Severo-Vostok SSSR), II. Publ. of the Acad. of Sci. of the USSR, 98-111.

———, 1953, On the investigation of Foraminifera in deep-sea bottom deposits of Okhotsk sea. *Reports of the Acad. of Sci. of the USSR* (Dokladi Akademii Nauk SSSR), **90** (2): 287-289.

———, 1953, New data on Foraminifera fauna in Okhotsk sea and on its distribution. *Trans. of Zool. Institute of the Acad. of Sci. of the USSR* (Trudi Zoologicheskogo Instituta AN SSSR). **13**: 12-32.

———, 1956, Foraminifera fauna from the Far East seas of the USSR. *Trans. of the Conferences on Problems and Themes of the Zoological Institute* (Trudi problemnih i tematicheskih sovestchanij Zoologicheskogo Instituta), **6**: 65-71.

Turpajeva, E.P., 1955, New species of Pantopoda found in the Kuril-Kamchatka trench. *Trans. of the Institute of Oceanology* (Trudi Instituta Okeanologii AN SSSR), **12**: 322-327.

Ushakov, P.V., 1952, *Chukotsk Sea and Its Bottom Fauna. Extreme Northeast of the USSR* (Krajnij Severo-Vostok Sojuza SSR) II. Publ. of the Acad. of Sci. of the USSR, 5-82.

———, 1952, Investigation of the deep-sea bottom fauna. *The Nature* (Priroda), No. 6: 100-102.

———, 1953, *The Fauna of Okhotsk Sea and Conditions of Its Existence.* Publ. of the Acad. of Sci. of the USSR, 1-459.

———, 1955, The influence of La Perouse Strait on fauna in the Southeastern part of Okhotsk Sea. *Reports of the Acad. of Sci. of the USSR* (Dokladi Aacademii Nauk SSSR), **105** (6): 871-1374.

———, 1955, Polychaeta from the Far East seas of the USSR. *Keys to the Fauna of the USSR* (Opredeliteli po faune SSSR), No. 56: 1-445.

———, 1955, Polychaeta of the family Aphroditidae in the Kuril-Kamchatka trench. *Trans. of the Institute of Oceanology* (Trudi Instituta Okeanologii), **12**: 312-321.

Vaguin, V.L., 1954, *Asteromyzostomum* n. gen.—a new species of the Myzostomida (Annelides). *Trans. of the Leningrad Society of Natural Sciences* (Trudi Leningradskogo O-va Jestestvoispytatelej), **72**: 16-37.

Vinogradova, N.G., 1954, Materials of quantitative investigations of the bottom fauna in some of the bays of Okhotsk and Bering seas. *Trans. of the Institute of Oceanology, Acad. of Sci. of the USSR* (Trudi Instituta Okeanologii AN SSSR), **9**: 136-158.

———, 1956, On the vertical distribution of the abyssal bottom fauna in the World Oceans. *Reports of the Acad. of Sci. of the USSR* (Dokladi Akademii Nauk SSSR), **110** (4): 684-687.

Zenkevich, L.A., 1955, *The Seas of the USSR, Their Fauna and Flora. Moscow:* State Publication Office for Pedagogical literature (Utchpedghiz). 371 - 409.

———, 1955, The importance of deep-sea research. *Trans. of the Institute of Oceanology* (Trudi Instituta Okeanologii AN SSSR), **12**: 5 - 15.

———, 1956, Recent oceanological investigations in the northwestern half of the Pacific. *Bull. of the Acad. of Sci. of the USSR*, geographical series (Izvestija Akademii Nauk SSSR), No. 4: 26-37.

Zenkevich, L.A. and Birstein, J.A., 1955, Investigation of the deep-sea fauna and questions arising thereon. *Bull. of the Moscow University* (Vestnik Moskovskogo Universiteta), No. 4-5: 231-242.

Zenkevich, L.A., Birstein, J.A. and Beljaev, G.M., 1954, Investigations of fauna in the Kuril-Kamchatka trench. *The Nature* (Priroda), No. 2: 61-74.

———, 1955, Investigations of the bottom fauna in the Kuril-Kamchatka trench. *Trans. of the Institute of Oceanology* (Trudi Instituta Okeanologii AN SSSR). **12**: 345-381.

Atlas of invertebrates of the Far East seas of the USSR. Moscow: Acad. of Sci. of the USSR., 1955.

Atlas of Oceanographic Basis for Fishery Chart of South Sakhalin and South Kuril Islands, **1**, 1955; **2**, 1956.

THE DEPENDENCE OF THE AMOUNT OF PHYTOPLANKTON UPON THE VERTICAL STABILITY OF THE SURFACE LAYERS IN THE BOREAL REGION OF THE PACIFIC

H.J. SEMINA

Academy of Sciences of USSR, Moscow, USSR.

(Abstract)

Phytoplankton flowering does not commence until the termination of the winter vertical circulation and the establishment of a suitable stability. This stability appears first in regions covered in winter by ice or receiving a considerable river discharge. The melted ice and fresh water diminish surface salinity and increase the stability.

In deeper areas without ice cover and not receiving river discharge, stability is notably lower, flowering begins later and the phytoplankton biomass never exceeds 2.5 grams under 1 sq. meter compared with several hundred grams in the neritic zone.

The amount of plankton in the neritic zone also depend on local conditions of stability and direct relationship have been established in several areas.

The maximal biomass of phytoplankton develops in areas where the thermocline is situated above the limit of phytoplankton and the position of the thermocline influences phytoplankton production.

Other factors also influence phytoplankton production and the relationship with water stability may in fact be only a statistical one.

THE INTERRELATIONS BETWEEN PHYTO- AND ZOOPLANKTON IN THE BERING AND OKHOTSK SEAS

C.W. BEKLEMISHEV

Academy of Sciences of USSR, Moscow, USSR.

(Abstract)

The relationship in time and space of copepod swarms and diatom blooms are of great importance in the cycle of organic matters in the sea. The paper considers the causes of direct and inverse relationships of copepods and phytoplankton from the West Bering Sea and the Sea of Okhotsk.

The term "animal exclusion" is used in cases where copepods are less numerous within a diatom patch than outside it. These "exclusions" may be due to grazing by the copepods or to differences in the development of adjacent plankton communities.

The term "edge effect" is used where the animals are most numerous along the edges of a diatom patch, although the amount of zooplankton within the patch may equal or be larger than that outside it. The "edge effect" is due, not to grazing but to differences in the seasonal states of the members of the community.

Examples of differences in seasonal or spatial occurrence of plankton are given and attention is called to the major differences between the neritic and oceanic communities always producing a state of "animal exclusion."

An "edge effect" is produced in autumn in the neritic area of the Bering Sea where seasonal sinking of the copepods is prevented by the shallowness of the water and their presence coincides with the second maximum of neritic diatom.

It is concluded that there is no general causes for plankton distribution, the major factors being the movement of biological seasons from the south northward and the difference of seasonal states of adjacent plankton communities.

BIOGEOGRAPHICAL PECULIARITIES OF THE PELAGIAL OF THE NORTHWESTERN PACIFIC

B.G. BOGOROV

Institute of Oceanology, Academy of Sciences of USSR, Moscow, USSR.

(Abstract)

Plankton investigations were carried out on the R/S *Vitiaz* in the northwestern part of the Pacific Ocean, from the Kurile Islands to about 35°N. permitting comparison of the fauna of the pelagial of subarctic water masses (boreal region) with that of the Kuroshio (tropical region).

This comparison evidenced an absence of subtropical fauna between the two regions, in the surface layers down to 200 and 500 m. There is a zone of mixing of water masses in the region of 40°-42°N.; the plankton here is both of subarctic and tropical origin, but no particular subtropical species occur.

The bulk of plankton concentrates in the region over the Kurile-Kamchatka trench; its biomass usually exceeds 50 mg. per 1 m^3. The quantity of plankton diminishes to the southward decreasing in the Kuroshio waters to less than 50 mg. per 1 m^3. Investigations of primary production show a 10-20 times greater production of carbon in boreal waters than in tropical.

A study of the vertical distribution of plankton shows that the great biomass of plankton in boreal waters is characteristic of all water layers from surface to bottom.

Consequently, there exist in the boreal region a number of conditions more favourable for plankton production than in the tropical region. Of paramount importance is the better mixing of waters and the upwelling of deep water layers bringing a rich supply of biogenic matter into the zone of photosynthesis; there is also a greater discharge of water from the continent, and in the surface zone a discontinuity layer which prevents the sinking of phytoplankton.

These conditions prevail through the whole water column and exert their influence on the biomass of benthos and the amount of organic matter of the bottom of the ocean. The paucity of organic matter in muds of the tropical region (in red clay) is due to the low production of plankton in the surface waters of the tropical regions.

ON THE ENDEMISM OF THE ABYSSAL OCEANIC ICHTHYOFAUNA OF THE NORTH PACIFIC

TH. S. RASS

Institute of Oceanology, Academy of Sciences of USSR, Moscow, USSR.

(Abstract)

Abyssal oceanic ichthyofauna of the northern waters of the Pacific (including those off the Kurile trench, Aleutian Islands, Alaska Bay, British Columbia, Oregon, Washington) consists mainly of the assemblage of species, with an admixture of Asiatic elements in the West and of the American ones in the East, consisting of the northern Bathylagidae *(Bathylagus milleri* and *B. pacificus)*, *Leuroglossus stilbius*, *Tactostoma macropus*, *Chauliodus macouni*, *Macropinna microstoma*, *Electrona arctica*, *Neoscopelarchoides* spp. (*linguidens* in the West, *dentatus* in the East), *Tarletonbeania* spp. (*taylori* in the West, *crenularis* in the East,) *Lampanyctus leucopsarus*, *L.nannochir*, *Diaphus protoculus?*, *Antimora microlepis*, *Coryphaenoides cinereus*, *C. pectoralis*, *Hemimacrurus acrolepis*, *Melamphaes rugosus*, *Oneirodes bulbosus* and *O. acanthias*.

The southern limit of distribution of the species of this basic group lies between 40°N. and 35°N. in the West and between Vancouver Island and North California in the East. To this basic abyssal oceanic ichthyofauna of the North Pacific some cosmopolitan species are admixed, e.g., *Cyclothone microdon*, *Alepisaurus aesculapius*, *Nemichthys avocetta*, etc. There are also some species of American origin. To the West Pacific abyssal fauna can be referred: *Gonostoma gracile*, *Lampanyctus jordani*, *Vitiaziella cubiceps*, *Podonema longipes*, *Coryphaenoides spinulosus* and *C. angustifrons*. To this group also can be referred some cosmopolitan species lacking in the East Pacific: *Sternoptyx diaphana*, *Anotopterus pharao*, *Ditropichthys storeri*, *Synaphobranchus pinnatus*, and *Polyacanthonotus challengeri*. Endemic for the eastern Pacific are *Lampanyctus regalis* (penetrating incidentally to the region of the Kurile trench), *Dolloa cyclolepis*, *Chalinura filifera*, and *Melamphaes cavernosus;* to the same group belong also some Macrourid species of the eastern part of the Bering Sea: *Coryphaenoides clarki*, *C. firmisquamis*, *Chalinura serrula* and *Ericara salmonea*.

In the waters off Honshu and the Hawaiian Islands, as also off South California and Central America the basis of abyssal oceanic ichthyofauna is different from that of northern Pacific. In this region there appear representatives of families lacking in northern waters: Argentinidae, Idiacanthidae, Stomiatidae, Astronesthidae, Eurypharyngidae, Regalecidae, Owstoniidae, Linophrynidae, etc.; there appear also a number of genera, replacing the northern ones such as *Rouleina*, *Chlorophthalmus*, *Myctophum*, *Notoscopelus*, *Maurolicus*, *Polyipnus*, *Argyropelecus*, *Yarrella*, *Lepidion*, *Lotella*, *Bathygadus*, *Gadomus*, *Coelorhynchus*, *Hymenocephalus*, *Malacocephalus*, *Lionurus* etc.

Hence there is a definite endemism of the abyssal oceanic ichthyofauna in the North Pacific; the northern Asiatic-American group of species differs appreciably from the American and the Asiatic groups of the tropical zone and these groups in their turn differ one from the other.

These different faunistic groups are connected only by some cosmopolitan species.

The distinct endemism of the Pacific Macrourids was shown by Hubbs (1930), the endemism of the abyssal oceanic ichthyofauna of the East Pacific was indicated by M. Grey (1956). The data collected by the R/S *Vitiaz*, compared to the data of other expeditions, show the existence of the three endemic groups of abyssal oceanic ichthyofauna in the North Pacific.

Symposium: *Equapac*

INTRODUCTION

A.L. TESTER

Bureau of Commercial Fisheries, U.S. Fish and Wildlife Service, Department of Interior, Washington, D.C., U.S.A.

After a period of informal discussions among interested oceanographic participants, both American and Japanese, a formal proposal for a quasi-synoptic oceanographic survey of the equatorial Pacific between approximately 20°N. and 20°S. latitude and from 135°W. to the Philippines was developed at the 1955 meeting of the Eastern Pacific Oceanic Conference. Further plans were formulated at the Norpac conference held in Honolulu in February, 1956, and at a meeting in Kobe, Japan in May, 1956. As a result of this series of discussions and of the plans submitted by each of the participants, a "standard" plan of observations was issued in July, 1956.

The survey was conducted during the general period August to October, 1956. Twelve vessels were involved: 7 Japanese, 1 French, and 4 American. These vessels represented a total of nine oceanographic and fishery organizations.

In general terms, each vessel undertook a program of standard Nansen bottle casts to 1,200 m. with frequent deeper casts to 3,000 m. or the bottom. Samples were drawn for salinity, phosphate, oxygen, silicate, total phosphorus, and deuterium analyses in varying degrees of consistency. Samples for radioactivity analysis were taken by most of the vessels at the surface and 500 m. and phytoplankton collections were made at several stations for similar determinations. Currents were measured in various ways including use of the *GEK*, drogues, and drift bottles. Biological observations included oblique plankton tows, C^{14} analysis, observations of bird flocks, fish schools, and mammals.

The details of the sampling conducted by the seven Japanese vessels are given in a descriptive paper by K. Suda and Shigeo Hikosaka which follows. Six of the seven Japanese vessels conducted meridional surveys which covered the western portion of the tropical and subtropical Pacific west of 175°E. longitude. The seventh, the *Daifuji Maru*, conducted experimental fishing north of Tahiti and as far east as 140°W. longitude.

French participation involved a cruise of the *Orsom III* to an area north of New Caledonia and Fiji arranged by the Institut Français d'Océanie. For the United States of America, Scripps Institution of Oceanography fielded two vessels, the *Horizon* operating west and south of Kwajalein and the *Stranger* operating west and south of Hawaii. In addition, the Pacific Oceanic Fishery Investigations of the U.S. Fish and Wildlife Service undertook an extensive oceanographic cruise of the *Hugh M. Smith* extending from 160°W. to 135°W. longitude.

Thus the area of interest was thoroughly covered in this multiple ship operation, except for a gap in the eastern tropical Pacific from 135°W. longitude to the coast of Central and South America. Some of the results are given in the papers which follow.

GENERAL REPORT OF JAPANESE PARTICIPATION IN "EQUAPAC"

K. SUDA and SHIGEO HIKOSAKA

Japanese Hydrographic Office, Tokyo, Japan.

History

In prewar time, most of the western part of the Pacific Ocean in the equatorial region was observed mainly by several survey vessels belonging to the Japanese Navy Hydrographic Office. Measurements were mainly made of the water temperature, salinity and the ocean current, but results from these observations could not be published until the end of World War II. After that time they were published in several volumes of the Japanese Hydrographic Bulletin.

On utilizing these materials to study the oceanography in the equatorial region, we keenly recognized the necessity of the cooperative observations by multiple ships in the same region at nearly the same period.

In addition, after the success of cooperative observations on "Norpac" operation by the United States, Canada, and Japan in the summer of 1955, we received a proposal to make cooperative observations in the equatorial region of the Pacific Ocean by the United States, France, and Japan in the summer of 1956, as mentioned in Dr. A.L. Tester's introduction. Hence we gladly agreed to it. On both operations, the senior author served as a coordinator for the Japanese operations.

Participating Agencies and Vessels

For operation "Equapac" the following six agencies and seven vessels of Japan joined.

1. *Satsuma* (July 28 to August 29, 1956), Japanese Hydrographic Office, Maritime Safety Board.
2. *Shoyo Maru* (August 29 to September 6, 1956), Japanese Fisheries Agency.
3. *Kagoshima Maru* (August 1 to August 20, 1956), *Keiten Maru* (July 25 to August 30, 1956), Faculty of Fisheries, Kagoshima University.
4. *Shunkotsu Maru* (May 26 to June 30, 1956), Shimonoseki Fisheries Institute.
5. *Daifuji Maru* (June 28 to October 1, 1956), Shizuoka Fisheries Laboratory, Shizuoka Prefecture.
6. *Umitaka Maru* (October 31 to November 13, 1956), Tokyo University of Fisheries.

The figures in brackets show the dates of the beginning and the end of the observations. As may be seen, the first four ships made observations mostly in August, but the other three vessels made observations in differing periods. These differences occurred for the following reasons.

The *Shunkotsu Maru* had the duty of observing the radioactive effects on ocean, marine organisms and atmosphere of the experimental H bomb explosion near Bikini and Eniwetok atolls in late spring, 1956.

The *Daifuji Maru* had the main object of conducting experimental tuna fishing in the sea near Tahiti and the *Umitaka Maru* had the duty of accompanying the *Soya*, a Japanese Antarctic expedition ship. Hence the period of observations was late.

Physical and Chemical Oceanography

Standard casts to 1,000 meters were generally made by each vessel except the ones to 800 meters by the *Shunkotsu Maru* and the ones to 1,200 meters by the *Kagoshima Maru.*

In addition, several deep casts were made to 2,000 meters by the *Umitaka Maru* and 3,000 meters by the *Satsuma* and the *Keiten Maru.*

Each oceanographic cast included observations of temperature, salinity and oxygen at each depth sampled except oxygen was not taken by the *Shoyo Maru.*

Silicates and phosphates were taken by the *Satsuma*, the *Shunkotsu Maru*, and the *Umitaka Maru.* In addition, pH determinations were made by the *Satsuma*, the *Shunkotsu Maru*, the *Daifuji Maru*, and the *Umitaka Maru.*

Current measurements by *GEK* or Ekman-Mertz type 2 current meters were made at selected stations by the *Satsuma*, the *Shunkotsu Maru*, and the *Umitaka Maru.* Drift bottles were released by each vessel except the *Shunkotsu Maru*, the *Daifuji Maru*, and the *Umitaka Maru.*

Samples for radioactivity analyses were taken at selected stations from the surface to 150 meters

by the *Shunkotsu Maru*, from the surface to 200 meters by the *Satsuma* and the *Daifuji Maru*, from the surface to 1,000 meters or 3,000 meters by the *Kagoshima Maru* and the *Keiten Maru*, and at the surface and 500 meters or at either depth by the *Umitaka Maru*.

Deuterium samples were taken at several stations by the *Satsuma* and the *Keiten Maru* for Woods Hole Oceanographic Institution.

Sea color and transparency were observed at each station except by the *Shoyo Maru*.

Additional *BT* observations were made every 30 or 60 miles by the *Satsuma* and at 18 stations by the *Umitaka Maru*.

Samples of iodide, iodate, strontium, arsenic, and total phosphorus analyses were taken at selected stations by the *Satsuma* and the *Shunkotsu Maru* for the Chemical Department of Nagoya University.

Meteorology

Weather observations were taken at each oceanographic and *BT* station. Regular weather observations were taken every hour by the *Kagoshima Maru* and the *Keiten Maru*, every 3 hours by the *Shunkotsu Maru*, every 3 or 4 hours by the *Daifuji Maru*, and at 144 stations by the *Umitaka Maru*.

Biology

Plankton tows were made at oceanographic or selected stations by the *Satsuma* from 0 - 150 meters, by the *Shoyo Maru* from 0 - 50 meters, by the *Kagoshima Maru* from 0 - 50 meters, 0 - 100 meters and 0 - 200 meters, by the *Shunkotsu Maru* from 0-150 meters, and by the *Daifuji Maru* from 0-150 meters.

Larval tows were made by the *Shoyo Maru* at 2100 hr. and also at sunset daily, by the *Daifuji Maru* on the surface at each oceanographic station, and by the *Kagoshima Maru* and the *Keiten Maru* at several stations. In addition, long-line fishing was conducted by the *Keiten Maru*, the *Shayo Maru*, and the *Shunkotsu Maru*. Visual observations of sea birds and wildlife were made by the *Satsuma*, the *Daifuji Maru*, the *Kagoshima Maru*, and the *Keiten Maru*.

Concluding Remarks

As may be seen from the above, there were many weak points in the Japanese participation in operation "Equapac" as follows:

1. Most of the Japanese vessels were too small for the ocean going navigation and had too small a cruising radius, hence they could not choose more suitable courses and needed frequent logistic support.

2. Most of the Japanese ships had different objectives. When opportunity was available they participated in operation "Equapac." Hence the period of the observations was not concentrated in August and extended over a longer period.

3. Most of the Japanese ships could not make the observations which were promised at the Honolulu meeting in February, 1956, because they did not have suitable instruments and equipment or they lacked observers.

In conclusion, it is a great regret to us that the informal request by Australia to extend operation "Equapac" by Japan to the Coral and Tasman seas could not be met because a suitable ship could not be diverted.

DISTRIBUTION OF WATER MASSES IN THE SURFACE LAYER OF THE EQUATORIAL PACIFIC

MICHITAKA UDA

Tokyo University of Fisheries, Tokyo, Japan.

(Abstract)

As one portion of the Equapac project, the author has plotted the distribution of temperature and salinity at the surface and 10m. (and also at 100 m. and 200 m. for comparison with the above).

Surface Salinity

The core of the north Central Pacific water mass is located between 15° and 30° N. latitude (its axis between 22° - 25°N.), 135°W. - 175°E. longitude, with salinities of 35.0 - 35.6°/$_{oo}$. Between 150°E. and 170°E., the salinities are higher than 35.5°/$_{oo}$. The core of the south Central Pacific water mass lies between 3°N. and 20°S. latitude with its axis between 13° and 19°S. The longitudinal extent is between 160°E. and 135°W. longitude. The salinities are high with values of 35.0 - 36.5°/$_{oo}$.

Between the two central water masses of high salinity lies a narrow zone of comparatively low salinity (33.5 - 34.5°/$_{oo}$) between 3°N. and 12°N., stretching from west to east and seemingly corresponding with the location of the Equatorial Countercurrent.

Surface Water Temperatures

Warm surface waters with temperatures higher than 29°C. were found between 12°N. and 25°N. (its axis, 17° - 20°N.), 132° and 145°E. longitude. Further south, the surface waters with temperatures higher than 29°C. lie between 8°N. and 8°S. (its axis at 6°N.), 135° and 160°E. longitude.

In the region west of 170°E. there is a zone of relatively low temperatures between 8° and 12°N.

In the region east of the 180th meridian, the conditions are quite different. There is a band of warmer water, the surface waters of the Equatorial Countercurrent, to either side of which are cooler waters of temperature less than 27°C. The cooler area south of the Countercurrent seems to be separated into two zones: one lies between the Equator and 3°S. and another between 3° and 10°S.

Salinity at 10m.

The distribution pattern of salinities at 10m. resembles that of the surface. At this depth, the core of the North Pacific central water mass shows an area of salinity higher than 35.0°/$_{oo}$ in the area bounded by 17° and 27°N., 140°W.-180° E. (its axis is between 18° and 19° N.), with an area higher than 35.5°/$_{oo}$ between the longitudes 150° and 170°E.

To the south, 10° - 20°S., the salinity at 10m. is between 36.0 and 36.5°/$_{oo}$ in the regions east of 140° E. Between 10° S. and 2° N., the salinities are higher than 35.0°/$_{oo}$.

Temperature at 10m.

As was the case with the salinities, the distribution pattern of the temperatures at 10 m. resembles that of the surface temperatures. The northern warm core (temperatures higher than 29°C.) lies between 12° and 25° N. (with its axis between 17° and 20°N.), 132° and 145°E. longitude. To the south, comparable temperatures lie between 8° N. and 10° S. latitude, 130° to 160° E. longitude.

There is a belt of warmer water lying between 10° and 13°N. which corresponds to the waters of the Equatorial Countercurrent. This belt extends from west to east and shows colder waters both to the north and to the south.

The colder waters to the south seem to be separated into two zones. One lying with its axis near the Equator (3°N. - 5°S.), east to the 180th meridian. This may correspond to the position of the Equatorial Undercurrent recently described by POFI.

Conclusion

The author points out that the Equapac data reveal a high saline Central Pacific water mass in both the Northern and the Southern Hemispheres. In the Northern Hemisphere maximum, the values are higher than 35.5°/$_{oo}$ in the area between 20° and 25°N. and 150° and 173°E. In the Southern Hemisphere maximum, the salinities

are between 36.0 and 36.6°/$_{oo}$ in the area between 10° - 20° S. and 165° - 135° W. The Southern Hemisphere maximum corresponds to the position of the atmospheric Pacific High Pressure System, a region of comparatively high evaporation and slight precipitation.

Between the Northern and the Southern Hemisphere maxima is an intermediate belt of warmer water and lower salinities (salinity minimum of between 33.5 and 34.5°/$_{oo}$ which corresponds to the position of the Equatorial Countercurrent (the subsurface waters at 100 and 200 m. clearly show cold, upwelled water) and the Equatorial Rainbelt.

The belt of cooler water lying along the Equator was evident and, at subsurface levels to 200 m., seemingly corresponds to the Equatorial Undercurrent.

SURFACE DYNAMICAL TOPOGRAPHY OVER 1000-DB SURFACE DERIVED FROM THE RESULT OF THE "OPERATION EQUAPAC" IN THE SUMMER 1956

KOJI HIDAKA

Geophysical Institute, Tokyo University, Tokyo, Japan.

(Abstract)

Using the data from the oceanographic observations made by the Japanese, the American, and the French research ships participating in Operation Equapac during the summer of 1956, a chart was drawn showing the dynamic topography of the surface over the 1000-db level in the equatorial Pacific between 20°N. and 20°S. latitudes. There is a remarkable contrast in the salient features of the surface contours between the eastern and the western halves of the Pacific. The surface of the sea slopes downward from the west to the east; the difference in sea level being about 70 dynamic centimeters. East of the 180th meridian, the sea surface along the Equator and the 10°N. parallel is lower than in the areas to the north or south of these latitudes. Thus, there is an elongated ridge in an east-west direction near the 5°N. parallel. Moreover, the sea level along this parallel rises from east to west. This feature is in good agreement with the results of the *Albatross* expedition as reported by Jerlov in 1953.

The surface topography west of the dateline is of somewhat different nature. The sea surface is in the form of a trough about the 5°-10°N. parallel and rises both to the north and the south. The highest sea surface, as measured during Operation Equapac, was at about 15°N. and 135°E.

Due to the differences in the pressure distribution in the tropical Pacific on either side of the 180th meridian, it may be expected that different circulation patterns will prevail between the eastern and western halves of the tropical Pacific Ocean.

THE DISTRIBUTION OF ARTIFICIAL RADIOACTIVITY IN THE EQUATORIAL REGION IN THE PACIFIC IN THE SUMMER OF 1956

Y. MIYAKE

Meteorological Research Institute, Tokyo, Japan.

(Abstract)

The radioactivity due to fission products in surface water samples collected at 69 positions near the equatorial region in the Pacific in the summer of 1956 was measured. The measurement of radioactivity was done by using the co-precipitation method in which a small amount of barium and iron were added to sea water as carriers. The results showed that the radioactivity was especially concentrated in the area 5°-15°N. and 145°-165°E. which is attributed to the transport of the radioactivity by the North Equatorial Current from the experimental ground. The highest activity of 193 dpm/l (as the value in July, 1957) was found at about 10°N. and 160°E. Only a trace amount of fission product was found in the area south of the Equator as well as east of 180°W.

THE EQUATORIAL COUNTERCURRENT AS SHOWN BY THE EQUAPAC OBSERVATIONS†

JOHN A. KNAUSS

Scripps Institution of Oceanography, University of California, La Jolla, California, U.S.A.

Since the first charts of Kerhallet and Findlay in 1851 and 1853, the Equatorial Countercurrent in the Pacific has nearly always been shown as a continuous current across the Pacific lying between 5° and 10° N. It is shown in this manner in such standard works as *The Geographic des Indischen und Stillen Ozeans* by Schott, and *The Oceans* by Sverdrup, Johnson and Fleming. Cromwell *(2)* has suggested that the Countercurrent exists in the eastern Pacific in August, but that contrary to the standard presentation, it is virtually absent from this region in February. The major basis for his conclusions are the series of monthly current observations published by the U.S. Navy Hydrographic Office *(1)*. These charts are based on the accumulation, through 1935, of all of the daily "current set" observations made by merchant and military ships which have cooperated with the U.S. Navy Hydrographic Office since the inception of this program in 1853 by Matthew, Fontaine and Maury, and are unique in that there has been a minimum of smoothing of the data. Fig. 1 shows a typical section of one of these current charts. The observations are grouped in one-degree squares. The number in the upper right hand corner gives the number of available observations for this square and the number in the lower left hand corner gives the mean current in nautical miles per day. The arrow gives the direction. Cromwell points out further that the Hydrographic Office charts indicate that during several months, the Countercurrent is discontinuous and is practically absent during April.

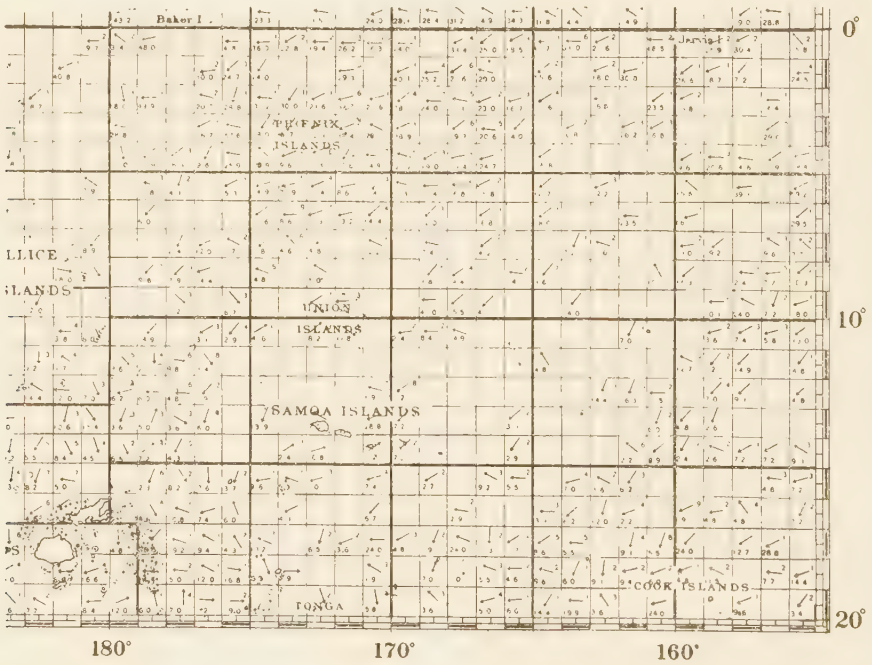


Fig. 1.—A portion of the U.S. Navy Hydrographic Office *Atlas of Surface Currents.*

† Presented by Dr. Warren C. Thompson.

As a background for studying the Equapac data, the question of the continuity of the Pacific Equatorial Countercurrent was re-examined for the western Pacific as well as the eastern Pacific. Using the Hydrographic Office observations, a series of Countercurrent charts was constructed, maintaining as nearly as possible, a strict interpretation of these data. In some areas and in some months observations are sparse, and it was necessary to interpolate between months.

It is not possible to arrive at a unique interpretation of these observations. However, the interpretation that seems most consistent with the observations is that the Equatorial Countercurrent is in two sections, one extending from the Coast of Costa Rica to the Marshall Islands and the other running from New Guinea to the Marshalls, and that furthermore, the Equatorial Countercurrent is missing in almost all areas in some months and is missing in some areas almost all of the time.

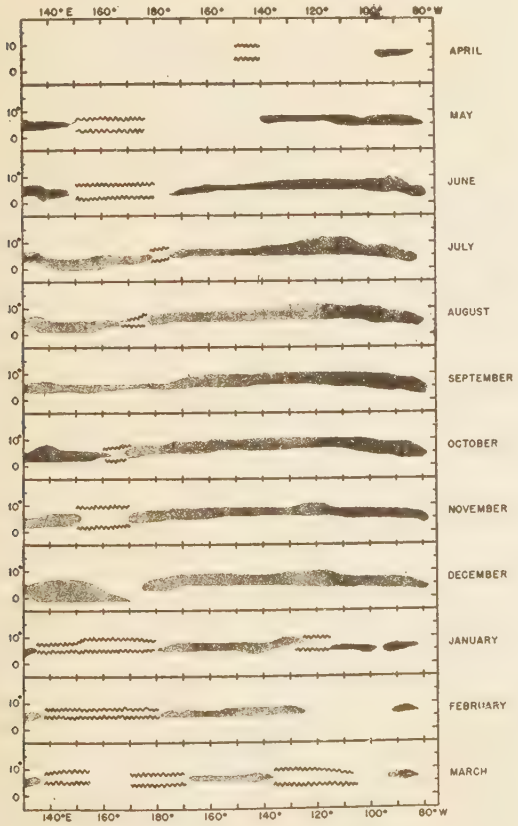


Fig. 2.—The Equatorial Countercurrent by months as interpreted from the USNHO *Atlas of Surface Currents*.

Figure 2 shows a schematic picture of the Countercurrent by months. The solid areas represent the areas where the Countercurrent is nearly always present during that month. The wavy lines mean that the current is present only some of the time.

In April the Countercurrent appears to be completely missing except in the region of 85° to 95° W. In May it begins to spread out from both coasts. In June the eastern section pushes farther out. In July the two sections nearly meet, but the western section is found at somewhat lower latitudes than the eastern section. In August and September the western sections move farther north. In November and December the western section begins first to retreat and then to push out near the Equator, which seems rather strange but is the only interpretation that one can make from the observations. Beginning in January, both sections of the Countercurrent begin to break up, and this process continues until we arrive at the minimum situation in April.

Having arrived at this rather unorthodox conception of the Pacific Equatorial Countercurrent from the mean surface current charts, the next step was to see if confirmation could be found in monthly charts of the mass distribution.

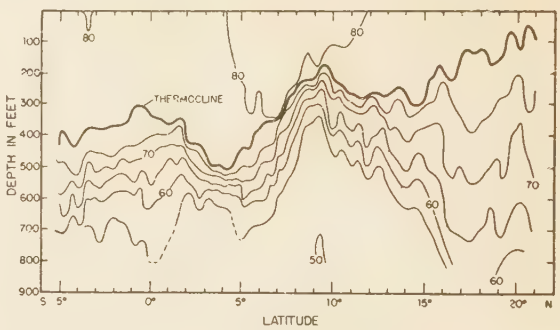


Fig. 3.—A typical *BT* section across the Equatorial Current System.

Fig. 3 shows a typical equatorial temperature cross section. In this example, both the North and South Equatorial Currents are well developed as is the Countercurrent. The criterion for the existence of a well developed Countercurrent is for the thermocline to become shallower to the north (or the temperature at the mean thermocline depth to become colder to the north). In this example a horizontal temperature chart at 400 feet would give a good representation of the position of the Countercurrent. Cromwell has

recently completed a chart of the mean thermocline depth by seasons in the eastern tropical Pacific. A discussion of this chart is to be presented in a paper at the Symposium on Upwelling. As will be discussed in that paper, his monthly thermocline charts are in reasonable agreement with his idea of a strong Countercurrent in late summer and a missing Countercurrent in late winter between 100° and 120° W.

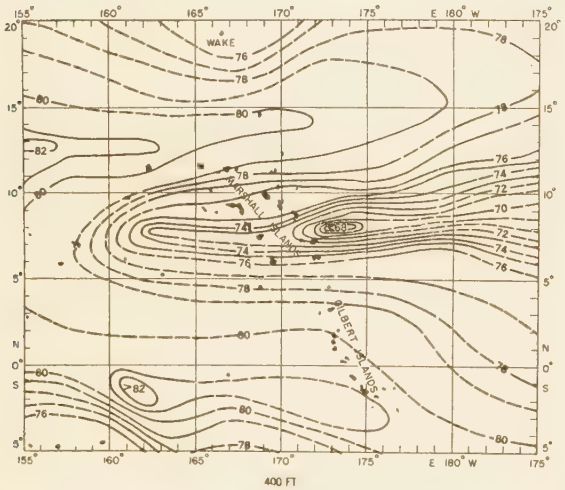


Fig. 4.—The mean temperature at 400 feet for February in the Marshall Islands area, *(Robinson, 1954)*.

For the Marshall Island area, we have the mean temperature charts published by Mrs. Robinson *(5)*. Her 400-foot chart for February shows a ridge of minimum temperature at about 80° N. from 175° W. to about 160° E. (Fig. 4). This is equivalent to the line of minimum thermocline height and represents the north boundary of the Countercurrent. The density of the isotherms is a measure of the intensity of the Countercurrent. The April chart, (Fig. 5), shows no such ridge and hence, no Countercurrent. The September chart, (Fig. 6), shows the ridge extending all the way across implying a continuous Countercurrent through this area. These three charts, as well as the others in Mrs. Robinson's publication, indicate good first order agreement with the idea of a two-section Countercurrent which is brought together in the summer.

A third way to check the accuracy of these Countercurrent charts is to compare them with the actual bathythermograph or hydrographic sections made by ships crossing the Countercurrent at different months in different seasons.

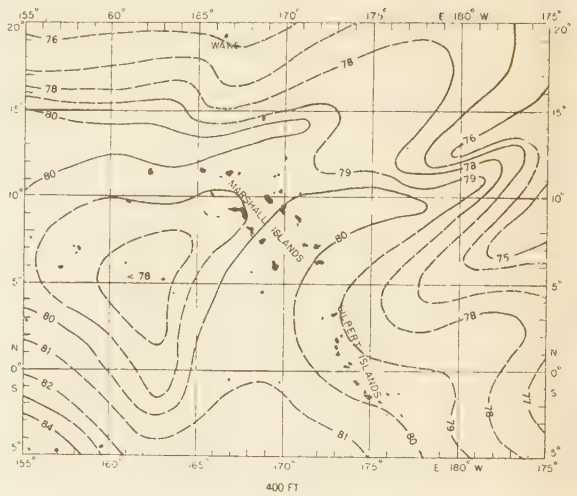


Fig. 5.—The mean temperature at 400 feet for April in the Marshall Islands area, *(Robinson, 1954)*.

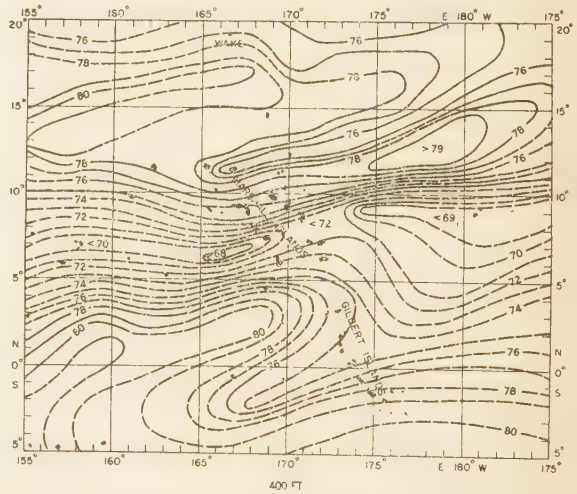


Fig. 6.—The mean temperature at 400 feet in September in the Marshall Islands area, *(Robinson, 1954)*.

A preliminary check of *BT* sections across the Countercurrent area indicates that these charts are essentially correct. However, it may be that the Countercurrent is a somewhat more persistent feature than is indicated by these monthly charts. The nature of the "current set" type of observation is to minimize the Countercurrent because unless a ship spends all or most of a 24 hour period in the Countercurrent, the net current drift may not be to the east. In months or longitudes where the Countercurrent is narrow or weak, the current set observations may miss the Countercurrent completely.

Most of the Equapac ships made their sections in August, a month in which the Countercurrent is reasonably well developed, and can be expected, at least some of the time, to reach across the entire Pacific. The Countercurrent was apparently observed on all sections by ships that made an approximate north-south traverse between 2° and 7°N.

The two crossings made by the *Horizon* at 157° and 164°E. show a split Countercurrent with most of the transport in the southern tongue. There is almost on transport in the northern tongue on the easternmost section. All of these eight sections by the *Kagoshima*, the *Keiten*, the *Satsuma*, and the *Horizon* were made in August.

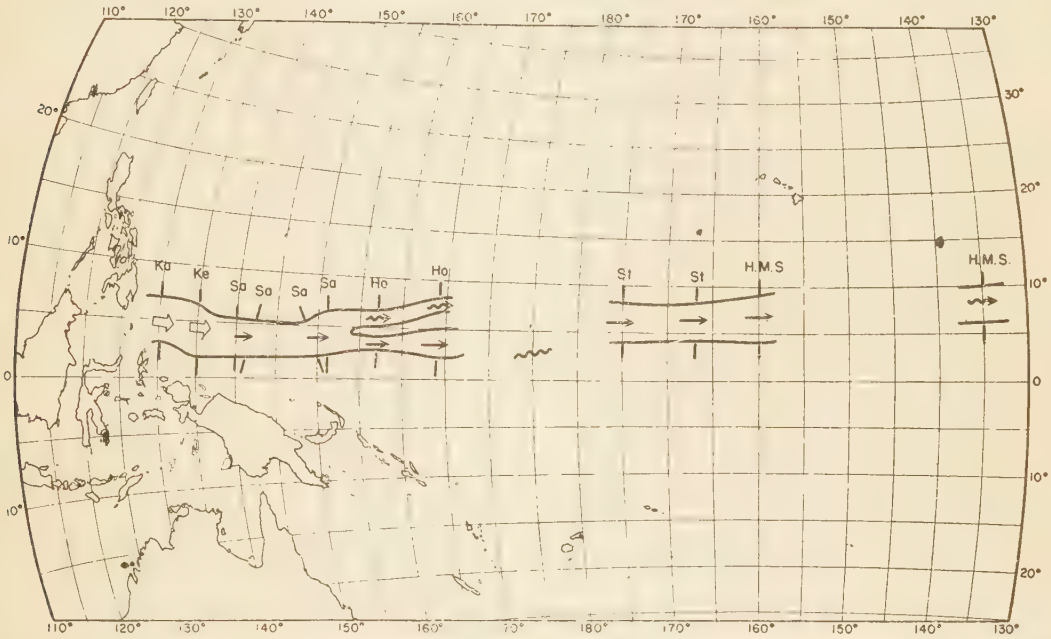


Fig. 7. — A preliminary presentation of the Equatorial Countercurrent for August-September, 1956 as interpreted from the Equapac data.

A detailed analysis of the dynamic topography, as observed during Equapac, is being made by Professor Hidaka. In Fig. 7 is shown a preliminary analysis of the Countercurrent as observed by Equapac ships. It should be noted that there may be changes in this picture resulting from Professor Hidaka's more complete analysis. Our work is based on the data from only those ships that made relatively straight north-south crossings of the Countercurrent.

A very strong, well developed Countercurrent was found by the *Kagoshima Maru* and the *Keiten Maru* at 130° and 135°E. respectively. A well developed, but not nearly as strong, Countercurrent was observed by the *Satsuma* on each of her four crossings between 140° and 151°E. Note that the Countercurrent appears to dip south about 200 km. between 135° and 140°E. as was indicated by the monthly charts.

Unfortunately, there is no north-south section between 165°E. and 175°W. The *Daifuji Maru* crossed the area on a line about 120°E. in the middle of July. Her data would seem to indicate that there was a Countercurrent of some sort north of 3°N. at 175°E., but it is not possible to tell whether or not the current was split or how strong it was.

The *Stranger*'s two sections were made in late August and the middle of September. They show a well developed Countercurrent between 4° and 8°N. at 175° and 167°W. There is no indication of a split in the current. Note that the Countercurrent at these longitudes is some 250-300 km. north of the strong southern section found at 165°E.

The *Hugh M. Smith* sections indicate the Countercurrent moving even farther north (between 6° and 10°N.) at 135°W. which is also in agreement

with the monthly charts. It should be noted that the easternmost *Hugh M. Smith* section indicated a weaker transport than either of the two *Stranger* sections or the western *Hugh M. Smith* section.

The conclusions one can draw from this preliminary analysis of the Equapac data are these. The Countercurrent is well developed between 130° and 145°E. and 160° and 175°W. It is less well developed and apparently split between 155° and 165°E. One cannot say with any certainty whether or not the Countercurrent was continuous from 130°E. to 130°W. during August, 1956. However, there is nothing in the Equapac data contrary to the hypotheses one arrives at by examining the U. S. Navy Hydrographic Office current set charts: that the Countercurrent is comprised of an eastern and western section; that the junction point of the two sections is at the approximate longitude of the Marshall Islands; and that the sections do not meet in winter, but may be continuous in summer.

REFERENCES

(1) *Anonymous*, 1947, Atlas of surface currents, northwestern Pacific Ocean, northeastern Pacific Ocean, southwestern Pacific Ocean *U.S. Navy Hydrographic Office*, *H. O. Pub.* No. 568, 569 and 570.

(2) Cromwell, T., 1957, Thermocline topography, horizontal currents and "ridging" in the eastern tropical Pacific. (Paper presented at 9th Pacific Science Congress, Symposium on Marine Upwelling in the Pacific, Physical Aspects). *Bull. Inter-Amer. Trop. Tuna Comm.*, **3**(3), 1958.

(3) Findlay, A.G., 1853, Oceanic currents and their connection with the proposed Central-American Canals, *Journal of the Royal Geographic Society*, **23**: 217-240.

(4) Kerhallet, C.P., 1869, General examination of the Pacific Ocean, *U.S. Navy Hydrographic Office Pub.* No. 5, (a translation from the second French edition).

(5) Robinson, M.K., 1954, Sea temperatures in the Marshall Islands area. Bikini and Nearby Atolls, Part 2. Oceanography (physical), *U.S. Geological Survey Professional Paper* 260 D.

(6) Schott, G., 1935, *Geographie des Indischen und Stillen Ozeans*. Hamburg: C. Boysen.

(7) Sverdrup, H.U., Johnson, M.W., and Fleming, R.H., 1942, *The Oceans*. New York: Prentice Hall Inc.

Symposium: *Techniques of Oceanic Productivity*

A RECENT SYMPOSIUM ON "MEASUREMENTS OF PRIMARY PRODUCTION IN THE SEA"

MAXWELL S. DOTY

Department of Botany, University of Hawaii, Honolulu, Hawaii.

The annual meetings of the International Council for the Exploration of the Sea in Bergen, Norway, was accompanied in late September, 1957, by a symposium entitled as above. The papers presented gave rather complete coverage of both the techniques and points of importance in evaluating the C^{14} and the oxygen techniques for measuring primary algal plankton production. Other methods were not considered extensively. The papers presented are expected to appear in a printed volume. The titles of these papers with their authors are presented below in order to promote discussion and correspondence. It is hoped that this presentation will also be useful in illustrating the current avenues of research on productivity to those concerned with Pacific Science.

Berge, Grim., The Primary Production in the Norwegian Sea June, 1954, as Measured by an Adapted C^{14} Technique.

Bernard, F., Données Récentes sur la Fertilité Élémentaire en Méditerranée.

Braarud, Trygve., Counting Methods for Determination of the Standing Crop of Phytoplankton.

Cooper, L.H.N., Consumption of Nutrient Salts in the English Channel as a Means of Measuring Production.

Corlett, John., Measurements of Primary Production in the Western Barents Sea.

Currie, R.I., Some Observations on Organic Production in the Northeast Atlantic.

Cushing, D.H., The Effect of Grazing in Reducing the Primary Production: a Review.

Cushing, D.H., Some Experiments Using the C^{14} Technique.

Cushing, D.H., The Estimation of Carbon in Phytoplankton.

Cushing, D.H., Nicholson, H.F., The Measurement of the Carbon Content of Diatoms, Using the C^{14} Technique: a Preliminary Note.

Davis, P.S., A Method for the Determination of Chlorophyll in Sea-Water.

Doty, M.S., Oguri, M., An Operational Description of the C^{14} Technique for Determining Primary Plankton Productivity.

Fedosoy, M., Investigation of the Chemical Base of Feeding Stuff and Productivity of Sea Basins.

Fogg, G.E., Extracellular Products of Phytoplankton and the Estimation of Primary Production.

Hanaoka, Tasuku., Suspended Matter as an Index of the Productivity of Sea Area.

Holmes, Robert W., Surface Chlorophyll *a*, Surface Primary Production, and Zooplankton Volumes in the Northeastern Pacific Ocean.

Jitts, H.R., The C^{14} Method for Measuring Co_2 Uptake in Marine Productivity Studies.

Kesteven, G.L., Laevastu, T. The Oceanographical Conditions for Life and Abundance of Phytoplankton Considered with Respect to Fisheries.

Ketchum, Bostwick H., Productivity in Relation to Nutrients.

Krey, J., Chemical Methods of Estimating Standing Crop of Phytoplankton.

Laevastu, T., Review of the Methods Used in Plankton Research and Conversion Tables for Recording the Data and Recommendations for Standardization.

Lucas, C.E., External Metabolites and Productivity.

Nielsen, Steemann., A Survey of Recent Danish Measurements of the Organic Productivity in the Sea.

Nielsen, Steemann., Experimental Methods for Measuring Organic Production in the Sea.

Nielsen, Steemann., Light and the Organic Production in the Sea.

Ohle, Waldemar., Diurnal Production and Destruction Rates of Phytoplankton in Lakes.

Rodhe, Wilhelm., The Primary Production in Lakes: Some Results and Restrictions of the C^{14} Method.

Steele, J.H., Production Studies in the Northern North Sea.

Wimpenny, R.S., Carbon Production in the Sea at the Smith's Knoll Lightvessel.

DISCUSSION

Dr. Anton F. Bruun, the Chairman, stated that the papers read at the Bergen Symposium would shortly be published in one volume. He then called on Sir Alister Hardy to speak on zooplankton production.

A.C. HARDY: *Suggestions for Zooplankton work in a new area.* In beginning any programme of estimating the varying quantity of zooplankton over an area, it is important to be certain that the nets being used for collecting the samples are suitable for the purpose and being used in such a way that they give reliable results. Sampling should be repeated at intervals throughout the 24 hours at one place, and also at a number of positions close together, say one-half mile apart, and as near together in time as possible, in order to test how representative of plankton in the neighbourhood a single net sample may be and also whether samples taken by day and by night give similar quantities. If such repeated hauls give widely different results, the method is inadequate for sampling a wide area by a series of single hauls taken only at intervals.

It may be found that longer hauls are necessary to overcome the effect of patchy distribution, or that samples must be taken closer together to give a reasonably good estimate of the varying zooplankton in the area. It is no use making extensive quantitative plankton surveys until such tests have been made to check the validity of sampling. In beginning work in any new area much time must be spent in such testing of methods and in devising, as a result of such tests, a suitable sampling technique for the particular area and type of plankton concerned.

I hope that a symposium on zooplankton productivity similar to that recently held at Bergen can be convened.

Dr. Anton F. Bruun, the Chairman, stated that it was planned to hold such a symposium as soon as possible.

The Chairman then called on Dr. Ryther, who commented on the Bergen Symposium. He stressed the limitations of the C^{14} technique, which gave relative productivity values, and urged that techniques should be developed to obtain absolute values. He described the recent work at Woods Hole in which potential productivity was estimated from the chlorophyl index of phytoplankton under optimum conditions. Two papers on this work have been published.

R.W. HIATT: Does the chlorophyl index give an indication of the physiological state of the phytoplankton?

J.H. RYTHER: We are investigating the relationship between chlorophyl elements, e.g., the ratio of chlorophyl to carotenoid pigments to indicate the physiological state of the organism. Physiological studies are extremely important in this work.

M.S. DOTY: Different organisms in different parts of the world may not produce same amounts of chlorophyl. A new dimension should be added.

J.H. RYTHER: In our studies of different organisms in different depths and temperatures and seasons we have been impressed by the consistency of the chlorophyl index independent of species or environmental conditions.

D.J. ROCHFORD: Can you relate total phosphorus to chlorophyl?

J.H. RYTHER: We find that total phosphorus in our water does not vary with chlorophyl content.

R.W. HIATT: With respect to the *FRNS III* and *Trieste* observations on coccoliths, there is the disparity in the results from different light effects particularly near the surface where there is ambient light. From *Trieste* a plankton net was used complementary to visual observations and results not yet worked up.

G.L. CLARKE: There is a great need for suitable quantitative techniques for sampling zooplankton, as stated by Dr. Hardy. It may be possible to use some chemical index for zooplankton productivity which may avoid complications of volume, dry weight, and wet weight measurements and which may compare with the chlorophyl index used in phytoplankton studies.

M.S. DOTY: We have found in some cases an almost perfect inverse relationship between carotenoid pigments in C^{14} productivity but are rather discouraged by not being able to find simple relationships between the different productivity factors.

Y. MIYAKE: The light distribution varies very considerably under different conditions and should be studied in relationship to plankton production.

T. R. FOLSOM: We think we have found a method using the naturally occurring potassium isotopes for the determination of plankton standing crop and I would be pleased to discuss this with anyone interested.

AN ANALYSIS ON THE PRODUCTION OF PLANKTON-FEEDERS IN OFFSHORE AREA OF JAPAN

YOSHIO HIYAMA and FUJIO YASUDA

Fisheries Institute, Faculty of Agriculture, University of Tokyo, Tokyo, Japan.

(Abstract)

The 30 years' landing statistics of the six major species of plankton-feeders caught in offshore waters around Japan show that the postwar total production of these species is nearly equal to prewar production following the significant war time depression.

An analysis was made, utilizing the statistics of the number of fishing boats and the catch of carnivorous fishes in the same area for the corresponding period.

The relative sizes of the populations of (1) economical plankton-feeders, (2) non-economical plankton-feeders and (3) carnivorous fishes in the area, and the changes caused by the man's fishing effort, are deduced from these figures.

In this area, with the highest fisheries production in the world, with a peak of two and half million metric tons per year, it is suggested that the economical plankton-feeders are being reduced, the non-economical plankton-feeders are increasing, and the carnivorous fishes are more or less constant in the postwar period compared with the prewar period.

The high demand for fish has permitted an "economic compensation" effect due to the public acceptance of previously less available or less popular species as substitutes for species formerly in strong demand. It is suggested that the consequent increased intensity of fishing has affected the balance of the populations of plankton-feeders over this vast area presumably constant in total productivity.

DISCUSSION

Y. HIYAMA: From anatomy (gill rakers), stomach contents and feeding experiments used to help interpretation of fish landings relative to plankton productivity.

R.W. HIATH: The relationship between plankton feeders and piscivorous fish where all organisms could be collected seems to be similar to your results for marine fish.

ON THE PRODUCTION OF COPEPODS IN THE BERING SEA

A.K. HEINRICH

Institute of Oceanology, Moscow, USSR.

(Abstract)

Samples numbering 1,010, collected by the R/S *Vitiaz* between 1950 and 1953, were used as a basis for the study of copepods production particularly with reference to cycles of propagation and development of the commonest species.

The areas covered by the sampling program were the northern and western regions of the Bering Sea.

The production of phytoplankton is similar in both regions whereas copepods production in the western region is 1/12 to 1/19 of phytoplankton production and in the northern region only 1/200.

Copepods production is related to that of phytoplankton and maximum production is achieved when older stages of the copepods are present during the period of phytoplankton maximum. Copepods production is less when phytoplankton maximum corresponds with the occurrence of the juvenile stages of the copepods.

MEASUREMENT OF LIGHT IN THE SEA

JOHN E. TYLER

Scripps Institution of Oceanography, University of California, La Jolla, California, U.S.A.

Although it is possible to make light measurements in the sea with instruments having a wide variety of geometrical configurations, and to obtain correlations between these measurements and biological activity, a much broader purpose is served by confining such measurements to established radiometric concepts. By so doing, the measurements themselves become more meaningful, an important uniformity is achieved in the data obtained by researchers in different laboratories, and the results obtained lend themselves readily to absolute calibration and to mathematical analysis.

The radiometric concepts that seem most useful in describing the submarine light field are radiance, irradiance, and spherical irradiance, or their visual counterparts: luminance, illuminance, and spherical illuminance. These are terms which have been adopted by the Colorimetry Committee of the Optical Society of America. The quantities themselves have exact mathematical definitions which dictate the optical procedure to be used in their measurement. For example, to effect a measurement of radiance it is necessary to restrict the solid angle of acceptance of light by the instrument, as well as its light collecting area; for the measurement of irradiance, it is important to collect light in accordance with the cosine law; for the measurement of spherical irradiance, it is necessary to use a spherical collector having specified properties.

Instruments for the measurement of these quantities were suggested as long ago as 1936 by Professor A. Gershun in his book entitled, *The Light Field.* Many of these suggestions have proved useful and have been incorporated into instruments for the measurement of light in the sea.

By proper use of Underwater Photometer with Fiat Plate Collector and Spherical Collector, it is possible to obtain values for four of the optical constants which describe the interaction of natural light with sea water.

Present-day theory provides for a total of eight optical constants to completely describe this interaction of light with water. The remaining four constants can be measured with a hydrophotometer, which measures the attenuation due to combined absorption and scattering and with nepholometer, from which can be obtained the total scattering coefficient and its components the forward and backward scattering coefficients.

It is not always necessary to measure all eight constants for the investigation of a specific problem. These eight constants are interrelated in such a way that a complete description of the water can be obtained from only four of them. In addition to this, there are certain practical problems in submarine visibility that can be solved if only two of the constants are known.

In the measurement of light in the sea, it is of the utmost importance to consider the spectral band width which is to be used. It is clear that each measurement will of necessity be associated with some spectral band width and that this band width will depend on the spectral energy distribution of the light being measured, the transmission of the water between the light source and the instrument, the transmission of the color filters in the optical system, and the spectral sensitivity of the phototube. Of these four factors, the only one that can easily be controlled is the transmission of the color filter. Thus, the only practical means of control over band-width lies in the choice of color filters. In this respect, there are three possible choices:

a.) The use of monochromatic filters of the type called interference filters. These filters have band widths of 10 millimicrons or less. They can be obtained for almost any region of the spectrum and when properly used are ideal for obtaining monochromatic measurements.

b.) The use of a "photopic" filter, that is a filter which when combined with the phototube—or other detector—will make the instrument "see" like a human eye. Such filters can be obtained for some photo-detectors but must be specially made for others. They should be used only when dealing with problems relating to the human eye.

c.) The use of actinic filters. By this we mean that a filter is chosen which, when used with the phototube, will have the same response characteristics as some specific organism under study. Under these conditions, the response of the instrument to light can be directly correlated to the

response of the organism to the same light. Such a filter can be used only when studying the specific organism for which the filter was designed.

The use of broad band filters, such as colored glass, or of no filter at all does not properly control the band width; and data taken through such filters will be difficult, if not impossible, to understand.

Up to now, we have spoken of the two major variables which must be controlled if measurements of the magnitude of light in the sea are to have full significance. These variables are controlled by restrictions on the manner of light collection and by restrictions on the selection of filters used to limit spectral band width.

The measurements described have been recommended primarily because of their usefulness in predicting light levels in the sea, in predicting the generation and degeneration of contrast in the sea, in separating the effect of absorption from that of scattering, and in making computations regarding the submarine light field.

We should not, however, leave the subject of light measurement in the sea without considering the application of these measurements to direct correlations with biological activity. In this respect, I can only suggest that it should be appropriate to use a spherical collector when studying the light response of small roundish organisms, because the manner of light collections in both cases corresponds. On the other hand, when dealing with organisms, or plants that grow on the bottom, it would seem more appropriate to use a flat plate light collector. In both cases it would be possible to report the light measurements with physical accuracy.

DISCUSSION

G.L. CLARKE: Can yon transform the data collected by a flat plate collector to its equivalent by a spherical collector?

J.E. TYLER: This is not possible theoretically, but in practice it may be possible.

THE MEASUREMENT OF BIOLUMINESCENCE IN THE SEA

GEORGE L. CLARKE

Harvard University and Woods Hole Oceanographic Institution, Massachusetts, U.S.A.

The investigation of the conditions of light in the sea has been greatly extended by the use of a bathyphotometer capable of responding to underwater illumination as low as 10^{-7} μw/cm² or about 10^{-12} of sunlight. For the photosynthesis of plants, light is required of an intensity at least equal to 1% of sunlight, and measurements of light of this order of magnitude have long been possible using the older photovoltaic cells. Animals, on the other hand, are capable of responding to light of very much lower intensity. We have evidence that fish can see small objects under an illumination of 10^{-10} of sunlight. Many types of planktonic animals carry out extensive diurnal vertical migrations to depths where the illumination is still weaker. In addition, many kinds of marine animals produce their own light by means of luminescent organs. The present study involved an investigation of the intensity, frequency, and duration of flashes of animal light in the sea and its ecological significance. The development of the bathyphotometer has made it possible to observe, measure, and record quantitatively the bioluminescence occurring at different levels in the sea.

Observations on the penetration of daylight into the sea were made along the Atlantic coast, particularly in the slope water southeast of New York and in the Sargasso Sea beyond the Gulf Stream. During the middle of the day the penetration of daylight could be measured to a depth of 600 m. Uniform transparency was encountered at the stations where measurements were made. The measurements were repeated in the middle of the night under conditions of no moon and clouds covering the stars. Under these conditions at the surface the light was only about 10^{-8} of that observed during the day. The intensity of light dropped off with depth at night at the same rate as during the day in the upper strata, but below a depth of 100 m. the flashes of luminescent animals tended to reduce the rate of light extinction. At depths greater than 400 m., bioluminescence tended to raise the level of illumination because of the overlapping of flashes.

Extension of the measurements to still greater depths was made possible by remodeling the bathyphotometer, building a stronger case, and providing a longer cable. Insulated conductors from the bathyphotometer were connected with a Sanborn recorder placed in the ship's laboratory. With this arrangement it was possible to obtain a continuous record of the conditions of light from the surface to depths as great as 1,700 m. and subsequently to 3,750 m.

When sample sections of the record are placed one above another on a chart, a synoptic view is obtained of the light conditions throughout the depth range studied. The record for the upper layers shows the diminishing light penetrating from the surface. As the photometer reaches greater depths, the flashes of luminescent animals are superimposed upon the background daylight. The number of flashes per minute increases to maximum at 900 m. At this level the background light received by the photometer may be more than a hundred times the dark level value of the instrument for five or more seconds at a time. At greater depths the number of flashes diminish. At night luminescent flashing is easily apparent on the record at 50 m. In the observations thus far made, flashing tends to increase at night to a maximum at about 100 m. and then to diminish. A second maximum is encountered at 900 m. followed by a gradual reduction in the amount of flashing. There is also a profound change in the nature of the flashing. Near the surface most of the flashes are of a very short duration, sometimes only a fraction of a second. At greater depths more prolonged flashing is encountered. Individual flashes or overlapping flashes may last for ten or twelve seconds. There is a general tendency for many of the larger flashes to reach their greatest brilliance within a second or two and then to die away more slowly. Some of the flashes are more than a hundred thousand times the intensity of the dark level of the instrument.

Actual counts of the number of flashes per minute for different size categories showed that during the day flashing could first be detected above the background light at about 400 m. and increased in frequency with depth to over 110 flashes per minute at 900 m. During the night, flashes reaches their greatest frequency of over

160 per minute at a depth of about 100 m. with a secondary maximum of over 90 flashes per minute at 900 m. It is of interest to note that this level of maximum flashing at 900 m. corresponds closely to the peak of population distribution report by Leavitt (1938) as determined by net hauls made in the same general region.

Measurements further off shore in deeper water showed a similar pattern in the occurrence of luminescent flashing. At depths greater than 1,700 m. the frequency of flashing continues to diminish, but occasional flashes as intense as those encountered near the surface were recorded. At depths greater than 2,700 m. the flashes were of reduced magnitude and generally occurred at a rate of less than one a minute. The photometer was very near the bottom, or possibly on it, for the measurement at the greatest depth in each of the two deepest series of observations.

For the foregoing measurements of bioluminescence the bathyphotometer was suspended in the inverted position so that its window received light from the hemisphere below it. The photometer thus reports the entire range of flashes, large and small, from all distances which are detectible within the hemisphere. In order to obtain some information as to the type of record that would be obtained from flashes made by known animals at known distances, calibration tests were made in the laboratory by placing animals in a light-tight box at a measured distance from the receiving surface of the photometer. In this way records were obtained of the flashes of the firefly *Photuris pennsylvanica* and of the ctenophore *Mnemiopsis leidyi*. Flashes were recorded of the latter at distances of 1, 37, and 80 cm. from the photometer for spontaneous light discharges and for discharges induced by electrical and mechanical stimulations. Certain peridinians and tintinnids, when placed within a few centimeters of the photometer, gave single flashes up to ten times the intensity represented by the dark level of the instrument. When a group of these protozoans, taken from a short plankton haul, were agitated near the photometer window the flashing produced an irregular record with the general illumination raised more than one hundred times.

In order to gain information as to the type of animal producing the luminescence at various depths, a new luminescence camera was employed. This instrument was designed and built by Dr. Harold E. Edgerton and Lloyd Breslau of the Massachusetts Institute of Technology. The device was attached to the cable supporting the bathyphotometer and was so designed as to cause flashing animals to take their own pictures. The luminescence camera consisted of two water-tight tubes mounted at right angles to each other. One of these contained a photomultiplier tube inside and an electronic flash bulb outside. The other contained the camera provided with 35 mm. "Plus X" film and operating mechanism. The film is automatically advanced one frame after each picture is taken. The field of view of the photomultiplier tube was limited by the sides of its window to a cone, and the base of the cone was limited by a baffle plate. The camera focused on the cone of water from within which the photomultiplier cell could receive light. Accordingly, when an animal swam or was carried into the sensitive area of the device, its flash was picked up by the photomultiplier tube which then set off an electronic flash. This extremely brilliant and rapid flash illuminated the area in the field of view of the camera and produced a sharp image of the flashing animal on the film. Pictures taken by the luminescence camera showed that many of the flashes are extremely small animals. However, one of the animals that took its own picture was a siphonophore swimming in a spiral about 5 cm. in diameter.

Bioluminescence has thus been found to provide detectible illumination at all depths investigated down to 3,750 m. The intensity, frequency, and duration of the flashes vary greatly and indicate the presence of very different populations at various depths. The brightness and varied pattern of bioluminescence in the sea, as now measured and recorded, suggests that it is probably of even more significance in the ecology of the sea than previously supposed.

DISCUSSION

Sir Alister Hardy congratulated Dr. Clarke on his work. He also remarked from his own observations that activities of nonluminescent animals stimulated luminescence in very small organisms.

The Chairman thanked all participants and contributors.

Dr. Doty and Sir Alister Hardy were asked to frame recommendations suitable for this area.

Publications

of the

NINTH PACIFIC SCIENCE CONGRESS

Abstracts of Papers, 1957	$ 2.00
General Programme	0.50
Proceedings*	
Volume 1 — Introductory and International Cooperation in Science	
Volume 2 — Animal Improvement	
Volume 3 — Anthropology and Social Sciences	
Volume 4 — Botany	
Volume 5 — Chemistry in the Development of Natural Resources	
Volume 6 — Coconut Problems	0.50
Volume 7 — Conservation	1.00
Volume 8 — Crop Improvement	
Volume 9 — Entomology	
Volume 10 — Fisheries	
Volume 11 — Forest Resources	1.00
Volume 12 — Geology and Geophysics	
Volume 13 — Meteorology	
Volume 14 — Museums	0.60
Volume 15 — Nutrition	
Volume 16 — Oceanography	2.50
Volume 17 — Public Health and Medical Sciences	
Volume 18 — Soil and Land Classification	
Volume 19 — Zoology	
Volume 20 — Climate, Vegetation, and Rational Land Utilization in the Humid Tropics	2.00
Map of Thailand, SCALE 1:2,000,000	0.50
Thailand, Past and Present	Out of print

* The Proceedings of the Congress will not be published in consecutive order. The price of each volume will be fixed after its publication, and will include surface mail postage to all countries.